

**STUDIES OF SEDIMENT CHEMICAL COMPOUNDS FROM RESERVOIRS
OF DIFFERENT TYPES**

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Abstract

This study presents chemical characteristics of sediments from different reservoir types and considers opportunities for sustainable management of investigated aquatic ecosystems. Bottom sediments are product of organic and inorganic nature, accumulated by settling of suspended substances of autochthonous and allochthonous origin during reservoir yearlong operation. In some reservoir sites wastes from fish farming become substantial part of bottom deposits. In terms of status management of the reservoir ecosystem including the health of growing aquaculture the accumulation of sediments often has negative consequences. Deposition of large amounts of organic matter is related to the process of its decomposition secured by the presence of high levels of dissolved oxygen, which sometimes might be depleted and might lead to oxygen deficiency.

Key words: bottom sediment; reservoirs; aquatic ecosystems; chemical characteristics of sediments

1. INTRODUCTION

The bottom sediments are formed by sedimentation of substances of autochthonous and allochthonous origin accumulated in a natural way during reservoir long-term exploitation. The waste products from fish breeding farms are an important part of sediments in reservoirs used for such activities. From point of view of both aquatic ecosystem management and proper breeding of fish culture the accumulation of bottom precipitants has a negative effect. The sedimentation of large quantities of organic substances and their subsequent mineralization requires high concentration of dissolved oxygen, which is not always available and thus oxygen deficiency might occur.

Some preliminary investigations characterized sediment chemical parameters from fishponds with intensive carp breeding providing the possibility to estimate the trophic value of this natural biological product (Hadjinikolova et al., 2007; Hadjinikolova and Stoeva, 2007; Hadjinikolova and Terziyski, 2011; Terziyski and Hadjinikolova, 2012). The bottom sediments are rich in organic substances, nitrogen, phosphorus, potassium and other macro and microelements accumulated in fishponds during their exploitation (Briggs and Funge-Smith, 1994; Hopkins et al., 1994; Krom et al., 1985; Smith, 1996; Jamu and Piedrahita, 2001; Boyd et al., 2002).

Differently from classical shallow fishponds the probability to observe oxygen deficit in hypolimnion of deep reservoirs is high. In such waters the aerobic decomposition of organic substances might be suppressed and the quantity of substances accumulated on the bottom increases. The processes of anaerobic decomposition start to prevail and some toxic substances like methane, hydrogen sulfide, ammonia are released. In that connection the goal of the present study is to characterize some chemical

sediment parameters from reservoirs of different type –the semi-mountainous „Kurdzhali” and mountainous „Dospat” reservoir.

2. MATERIALS AND METHODS

2.1. Studied water bodies

The „Kurdzhali” and „Dospat” reservoirs were sampled during July 2009 - April 2010 and April - November 2011 periods. The reservoirs were chosen due to their geographic characteristics and usage for fish breeding in cages.

2.2. Altitude and situation: The „Kurdzhali” is a semi-mountainous reservoir with an altitude of 300 - 350 m and coordinates 41°38'24" Northern latitude and 25°18'21 East longitude. The „Dospat” is mountainous reservoir situated on 1200 m above sea level, 41°41'54`` East longitude and E 24°05'10`` East longitude.

***Flooded area:** „Kurdzhali” reservoir has an area of 16 070 000 m² while the area of „Dospat” reservoir amounts to 22 000 000 m².

***Duration of fish farm exploitation:** It amounts to more than 30 years for both reservoir

***Bred fish species:** There are sturgeon and carp fish farms in „Kurdzhali” reservoir, while in „Dospat” reservoir only trout farms are available.

2.3. Sampling stations

A representative number of reservoir sampling stations were chosen, depending on the reservoir flooded area and the distribution of fish cages in them. There are six sampling stations selected in „Kurdzhali” reservoir as follows: station No 1 (N 41°37'68``; E25°19'99``) situated about 300m from the dam; station No 2 (N 41°37'83``; E 25°19'55``) situated close to cage farm „Vinikol” OOD; station No 3 (N 41°38'48``; E 25°18'71``) situated in proximity of cage farms „Aqua-mash” and „Aqua-belouga” station No 4 (N 41°38'52``; E 25°18'71``), situated close to cage farms „Esetra comers” Ltd., station No 5 (N 41°38'73``; E 25°17'73``) and station No 6 (Khalach dere (N 41°39'64``; E25°16'40``) are situated in the free water area of the reservoir.

In „Dospat” reservoir there are also six sampling stations selected as follows: station No1 (N 41°38'69``; E 24°09'13``) is situated 50 m from the dam; station No 2 (N 41°39'45``; E 24°09'06``), station No 3 (N 41°39'80``; E 24°09'18``) and station No 4 (N41°39'72``; E 24°8'89``) are situated around the cages of „Salvelinus-Rea Fish” farm, while station No 5 (N 41°40'41``; E 24°07'46``) and station No 6 (N 41°42'45``; E 24°04'55``) are situated in the free water area of the reservoir.

2.4. Collection and processing of sediment samples

The samples were collected monthly and seasonally during the period July 2009 – November 2011 according to scheme prepared in advance. The sediment layer 0 - 15 cm was sampled by bottom sampler taking into account all requirements for this kind of sampling. The sample preparation for analysis includes drying at 100 - 105 °C to air dry weight and grinding to particle size smaller than 2 mm. The sediment analysis also includes the pH measurement in water extract (active acidity - AK) and in salt extract (exchangeable acidity - OK) by means of pH-meter WTW/SET type; determination of organic nitrogen by Kjeldahl after mineralization with Selenium by means of the half automatic system for analysis type DK-6 for decomposition and UDK-132 for distillation manufactured by VELP-Scientifica; percentage (%) determination of the mobile nitrogen forms spectrophotometrically after previous extraction from soil by means of KCl solution; determination of inorganic forms of phosphorus by double lactate method of Egner-Riem (after Tomov et al., 1999).

3. RESULTS AND DISCUSSION

3.1. „Kurdzhali” reservoir

The chemical data of bottom sediments from „Kurdzhali” reservoir during the 2009 - 2010 period are presented in Table 1 and those of 2011 period in Table 2.

The hydrogen index (pH). The absolute values of active acidity (determined by soluble acids and soil salts) are varying between 4.32 and 6.60 while the station means are in the interval 5.09 (st. No 1) - 5.84 (st. No 3). The exchangeable (potential) acidity shows absolute values lower than those of active acidity, varying in the range 3.82 - 6.59 and station means changing from 4.82 (st. No 5) to 5.72 (st. No 3). In year 2011 the absolute data of active acidity are varying between 5.22 and 7.45, while the means amount to 6.01 (st. No 3) and 6.60 (st. No 6). The absolute values of exchangeable acidity are lower than those of active acidity and are varying in the range 4.89 - 7.28, while the means are in the interval 5.63 (st. No 3) - 6.33 (st. No 6).

Inorganic nitrogen forms, ammonium ions ($\text{NH}_4\text{-N}$, mg.kg^{-1}). The concentrations of ammonium ions vary in wide ranges - from 7.88 mg.kg^{-1} (st. No.3) to 175.5 mg.kg^{-1} (st. No2). For the remaining stations the ammonium ions are between 10.63 mg.kg^{-1} and 38.8 mg.kg^{-1} . During the second investigation period concentrations of ammonium ions change between 1.0 mg.kg^{-1} (st. No 6) to 128 mg.kg^{-1} (st. No 1). For the remaining stations the ammonium ions are in concentrations between 13.25 mg.kg^{-1} and 90.5 mg.kg^{-1} . The level of ammonium ions concentrations from all samplings close to dam (st. No 1 and 2) remain relatively high for the investigation period.

Inorganic phosphorus forms ($\text{PO}_4\text{-P}$, mg.kg^{-1}). The values obtained for concentrations of inorganic phosphorus forms vary in wide limits which for the first period are in the range (0.6 mg.kg^{-1} (st. No 6) to 355.39 mg.kg^{-1} (st. No 4), and during the second period from 20.5 mg.kg^{-1} (st. No 1) to 166 mg.kg^{-1} (st. No 6). During the investigation station No 4 shows higher values in the first period (in the proximity of cages) while in the second period the same is valid for st. No 3 and 4 (situated around the cages) and for station No 6.

Organic nitrogen (ON, %). The levels of organic nitrogen percentages during the 2009 -2010 period varied between 0.08 % - 0.89 %. The maximum absolute values were encountered in the zone of station No 4 in September 2009 (0.89 %) and April 2010 (0.75 %). Seasonal means of organic nitrogen for single stations are varying from 0.26 % to 0.65 %, with a tendency to higher percentages in the zones of st. No 4 (0.65 %), No 5 (0.45 %) and No2 (0.32 %). During the second investigation period the percentages of organic nitrogen absolute values vary from 0.10 % (st. No 6) to 0.78 % (st. No 3), while the means change from 0.24 % (st. No 6) to 0.62 % (st. No 3). High percentage levels were also encountered in the zones of cage farms (st. No 3 and No 4) in April and November 2011.

3.2. „Dospat” reservoir

The data of all chemical parameters from „Dospat” reservoir for interval 2009 - 2010 are presented in Table 3 (first investigation period) and Table 4 (second period).

The hydrogen index (pH). The 2009 - 2010 data showed that the absolute values of active acidity for single stations varied within the limits 3.98 (st. No 4) - 6.44 (st. No 3), while the station means change from 4.09 (st. No 5) to 5.09 (st. No 3) correspondingly. The exchangeable acidity shows lower absolute values than those of active acidity, which are in the range 3.49 (st. No 4) - 6.46 (st. No 3) and the means vary between 3.65 (st. No 5) and 4.79 (st. No 3). During the second investigation period the active acidity values varied within the limits 4.26 (st. No 4) - 5.46 (st. No 3), while the exchangeable acidity were in the range 3.74 (st. No 5) - 4.86 (st. No 3) and were lower than those of active acidity. The station means are within the limits 4.53 (st. No 1) - 4.80 (st. No 3) for active acidity and change from 3.96 (st. No 1, st. No 4 and st. No 5) to 4.51 (st. No 3) for exchangeable acidity.

Inorganic nitrogen forms, ammonium ions ($\text{NH}_4\text{-N}$, mg.kg^{-1}). During 2009 – 2010 the concentration of ammonium ions varied between 10.38 mg.kg^{-1} (st. No 1) – 186.0 mg.kg^{-1} (st. No 3). Within the investigation period the level of ammonium ions were relatively high in July in the zones of st. No 2 и st. No3. For the remaining stations concentrations of ammonium ions reported range from 30.88 mg.kg^{-1} to 47.50 mg.kg^{-1} for st. No 4 and from 25.00 mg.kg^{-1} (September, 2009) to 36.88 mg.kg^{-1} (April, 2010) for st. No 5. For remaining stations concentrations of ammonium ions reported vary from 30.88 mg.kg^{-1} to 47.50 for st. No 4 and from 25.00 mg.kg^{-1} (September, 2009) to 36.88 mg.kg^{-1} (April, 2010) for st. No 5. Mean values are varying in the range 30.94 mg.kg^{-1} (st. No 5) - 78.96 mg.kg^{-1} (st. No 2). In 2011 the measured characteristics shows lower values within the interval 5.00 mg.kg^{-1} (st. No 3, August) - 70.50 mg.kg^{-1} (st. No 2, June) Means values in year 2011 varied within the limits 33.25 mg.kg^{-1} (st. No 4) - 46.63 mg.kg^{-1} (st. No 2).

Inorganic phosphorus forms ($\text{PO}_4\text{-P}$, mg.kg^{-1}). The concentration of phosphate ions in 2009 – 2010 period varied in the range 14.07 mg.kg^{-1} (November 2009, st. No 2) – $246.11 \text{ mg.kg}^{-1}$ (April, 2010, st. No 4). During the second investigation period the level of inorganic phosphorus forms varied from 49 mg.kg^{-1} (April, st. No 2) to 398 mg.kg^{-1} (June, st. No5). In the period of investigation the phosphate levels are lower in August ($49 - 128.5 \text{ mg.kg}^{-1}$) with higher values reported in the zones of stations No 3 and No 4. On st. No 1 there are some seasonal variations from $67 - 82 \text{ mg.kg}^{-1}$ (August - October, 2011) to $124 - 143.5 \text{ mg.kg}^{-1}$ (April - June, 2011).

Organic nitrogen (ON, %). The percentages of organic nitrogen in sediments during the first sampling period varied from 0.13% (November 2009, st. No 3) to 0.96% (July 2009, st. No 3). Higher values for organic nitrogen were reported on st. No 4 (0.44%) and st. No 2 (0.92%) in April 2010. The seasonal station mean values of organic nitrogen are in the range 0.49% - 0.79% . There is a tendency to higher levels on st. No 2, st. No 3 and st. No 4 ($0.65 - 0.79 \%$), i.e. in the proximity of cage facilities with highest values on st. No 2. The percentages of organic nitrogen in sediments during the second period varied from 0.04% (st. No 5) to 1.47% (st. No 3), with maximum values reported in April 2011 in the zones of st. No 3 and st. No 4 (1.28%), in June in proximity of st. No 6 - 1.29% , and in October 2011 for st. No 3 - 1.07% . There is a tendency to higher levels on all sampled stations in April 2011 ($0.86 - 1.47 \%$), i.e. in the period of spring complete mixing.

The data indicate a certain differentiation in values of active and exchangeable acidity on single sampling stations. In „Kurdzhali” reservoir during the first sampling period higher acidity is observed in proximity of st. No 5, i.e. the main river inflow and during the second period in proximity of st. No 3, where the cage farms Aqua-mash and Aqua-beluga were situated. In „Dospat” reservoir during the first sampling period higher acidity is observed in proximity of st. No 5, i.e. the main river inflow and during the second period in zones of st. No 4, and st. No 5 As a whole the bottom sediments of investigated reservoirs show acidity below 7.0 ($\text{pH} < 7.0$) differently from sediments of carp fishponds whose pH values are in the alkaline region ($\text{pH} > 7.0$) (Hadjinikolova, 2007). Most probably this is connected with the prevailing processes of decomposition in deep layers of reservoirs as result of which mainly acid substances (methane, hydrogen sulfide, humic and other acids) are released. According to Boyd (1992) the pH level between 7.5 и 8.5 is favorable for decomposition of organic matter in waters.

The registered higher values of ammonium ions in vicinity of the dam (st. No 1) and in zones of cage farm facilities (st. No 2, 3, 4) in both reservoirs are explained most probably by allochthonous transport and internal load with organics as a result of active feeding and seasonal dynamics of plankton assemblages.

The „Kurdzhali” reservoir study reveals higher values for concentration of phosphate ions in the zones of cage farm facilities and of main river inflow. The most concentrations of phosphate ions in zones of cage farm facilities of „Dospat” reservoir during the first period of sampling are below 50.0 mg.kg^{-1} , while during the second sampling period (April - June 2011) higher levels for all sampling stations are

observed (103.0 - 398.5 mg.kg⁻¹). The highest absolute value is measured in the reservoir inflow region which is probably result of anthropogenic influence from this period. This fact might explain the higher phosphorus accumulation in reservoir than in fishpond sediments (7.45 - 16.36 mg.kg⁻¹), (Hadjinikolova, 2007).

Usually the nitrogen do not limit the biological activity in freshwater ecosystems, while the phosphorus increase might lead to eutrophication problems like mass development of phytoplankton and high turbidity of the water column (Kajak, 1995; Kasza, 1995; Straskraba et al., 1995).

The summarized results of sediment investigations of „Kurdzhali” and „Dospat” reservoirs show a tendency towards higher levels of organic nitrogen in the zones of cage farm facilities and in regions of main river inflow, which are more clearly expressed for „Dospat” reservoir. The higher percentages of organic nitrogen in the zones of cage farm facilities are due to reservoir organic loading caused by applied excessive food and fish breeding, while in the main river inflow regions the organic load is result of anthropogenic influences of different origin. Bearing in mind that the total content of organic nitrogen in soil surface layers varies within the range 0.1 – 0.85 % (Atanasov et al., 1979), one might assume that the organic nitrogen accumulation in sediments for investigated period and zones of „Kurdzhali” reservoir is medium to high and that of „Dospat” reservoir is high. According to this characteristics the sediments of investigated reservoirs are different from those of carp fishponds (0.21 - 0.33 %), where the accumulated organic nitrogen is considered low (Hadjinikolova, 2007).

4. CONCLUSIONS

The bottom sediments of studied reservoirs show acidity bellow 7 units (pH < 7.0), and the zones towards the main river inflow are distinguished by higher acidity.

There is a horizontal differentiation of nutrient concentrations with highest values registered in the zones of cage farm facilities, however, in main river inflow region of „Dospat” reservoir the tendency to phosphate increase is more clearly expressed (about 398.5 mg.kg⁻¹), which is probably result of anthropogenic impact.

The organic nitrogen accumulation in bottom sediments from investigated reservoirs vary from medium to high (0.1 % - 0.85 %) compared to reported percentage of organic nitrogen in soil surface layers.

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Table 1. Data of chemical parameters from sediments of Kurdzhali reservoir for the period May 2009 – April 2010 (first sampling period)

Year Date	Station No	Parameters				
		pH (AK)*	pH (OK)**	NH ₄ -N mg.kg ⁻¹	PO ₄ -P mg. Kg ⁻¹	Org. N %
2009						
27.07.	3	6.6	6.59	7.88	6.14	0.0802
	4	6.01	5.7	10.63	145.81	0.6375
11.09.	1	6.07	5.78	129.5	29.04	0.2597
	3	5.8	5.72	16.75	81.74	0.2881
	4	5.64	5.37	25.75	355.39	0.8929
	5	6.01	5.77	30.88	147.31	0.5041
18.11.	2	5.99	5.79	175.5	76.50	0.2788
	3	5.50	5.26	29.13	169.76	0.4578
	4	5.07	4.95	28.75	180.24	0.3728
	5	4.31	3.82	38.88	45.51	0.6936
2010						
15.04.	2	5.52	5.42	26.13	88.85	0.3540
	3	5.40	5.29	33.50	92.22	0.2598
	4	5.08	4.90	26.38	12.57	0.7496
	5	4.96	4.87	33.50	150.30	0.6093
	6	5.28	4.96	29.00	0.60	0.3164

*AK –active acidity; **OK – exchangeable acidity

Table 2. Chemical composition of sediments in Kurdzhali reservoir in year 2011 (second sampling period).

Date	Station No	pH(AK),	pH(OK),	NH ₄ -N mg.kg ⁻¹	PO ₄ -P mg.kg ⁻¹	Org. N %
2011						
12.04.	1	5.44	4.89	31.75	68.5	0.4795
	3	5.22	4.98	32.75	0	0.6687
	4	5.9	5.54	13.25	119.5	0.7242
	5	5.54	5.12	31.00	103	0.4655
	6	5.68	5.29	37.00	166	0.4367
22.06.	1	6.24	6.01	75.50	61	0.4065
	3	5.63	5.44	31.25	149.5	0.6395
	4	5.7	5.51	30.50	0	0.6389
	5	6.58	6.04	90.50	88	0.38
	6	6.66	6.58	10.50	61	0.25
27.07.	1	6.39	6.14	128.00	56.5	0.3489
	3	5.78	5.37	62.50	95.5	0.4794
	4	6.28	5.98	62.00	148	0.5224
	5	6.31	5.78	44.50	64	0.36
	6	7.02	6.92	12.00	29.5	0.17
23.08.	1	7.13	6.68	27.00	65.5	0.2616
	3	6.42	5.88	26.50	98.5	0.5087
	4	6.92	6.40	32.50	145	0.4505
	5	6.95	6.17	33.50	64	0.30
	6	7.45	7.28	1.00	35.5	0.10
1.11.	1	6.90	6.15	57.50	20.5	0.1705
	3	7.02	6.49	38.50	124	0.7787
	4	6.24	5.56	18.50	103	0.7049
	5	6.72	5.87	29.50	53.5	0.30
	6	6.20	5.60	16.50	163	0.24

Table 3. Data of chemical parameters from sediments of Dospat reservoir for the period May 2009 – April 2010 (first sampling period)

Date	Station No	Parameters				
		pH (AK)	pH (OK),	NH ₄ -N mg. kg ⁻¹	PO ₄ -P mg. kg ⁻¹	Org. N %
2009						
24.07.	2	*	*	185.5	42.51	0.6847
	3	-	-	186.0		0.957
	4	-	-	47.5		0.2498
24.09.	1	4.12	3.82	39.38	47.01	0.543
	3	4.21	3.87	29.88	42.51	0.6668
	4	4.06	3.71	36.38	44.01	0.7793
	5	3.99	3.57	25.00	39.52	0.3354
12.11.	1	4.19	3.75	10.38		0.5529
	2	4.14	3.68	24.00	14.07	0.7512
	3	6.44	6.46	25.25	44.01	0.1275
	4	3.98	3.49	30.88	35.03	0.7416
2010						
28.04.	1	4.22	3.80	39.38	44.01	0.3724
	2	4.45	4.03	27.38	54.49	0.9204
	3	4.63	4.05	24.75	33.53	0.8552
	4	4.44	4.06	31.5	246.11	0.9044
	5	4.19	3.73	36.88	24.55	0.8348
	6	4.11	3.74	30.88	35.03	0.7132

Table 4. Chemical composition of sediments in Dospat reservoir in year 2011 (second sampling period)

Date	Station No	pH (AK)	pH (OK)	NH ₄ -N mg.kg ⁻¹	PO ₄ -P mg.kg ⁻¹	Org. N %
2011						
27.04.	1	4.53	4.04	34.00	124	0.8623
	2	4.94	4.36	36.50	103	1.0812
	3	5.46	4.86	32.75	140.5	1.4689
	4	4.26	3.75	45.50	148	1.2819
	5	4.32	3.74	40.75	113.5	1.0615
	6	4.65	4.03	22.75	118	0.8727
28.06.	1	4.53	4.00	59.50	143.5	0.7114
	2	4.68	4.00	70.50	211	0.8132
	3	4.83	4.15	59.00	170.5	0.7109
	4	5.08	4.34	45.50	181	0.7848
	5	4.92	4.17	51.50	398.5	0.9008
	6	5.01	4.38	64.00	151	1.293
29.08.	1	4.55	3.97	35.50	67	0.5084
	2	4.43	3.90	39.50	49	0.8577
	3	4.97	4.41	5.00	100	0.9587
	4	4.52	3.99	34.50	128.5	0.8082
	5	4.63	4.07	48.50	83.5	0.5413
	6	4.63	4.10	23.00	83.5	0.4524
24.10.	1	4.50	3.82	50.50	82	0.3039
	2	4.79	4.15	40.00	179.5	0.7047
	3	5.26	4.60	69.50	109	1.0758
	4	4.38	3.76	7.50	82	0.0667
	5	4.51	3.87	19.50	178	0.0371
	6	4.82	4.09	30.00	143.5	0.5564

REFERENCES

1. Atanasov I., T. Totev, S. Stefanov, G. Dimitrov, P. Gribachev (1979) Manual to exercise, Zemizdat, S., 64–83. (in Bulgarian)
2. Tomov T., G. Rachovski, Sv. Kostadinova, I. Manolov (1999) Agrochemistry Seminars Textbook. Agricultural University, Plovdiv, 110 pp. (in Bulgarian)
3. Hadjinikolova L., D. Terziyski, A. Stoeva, 2007 Characteristics of some chemical parameters of the slime from carp basins. *Journal of animal science*, 4: 64-68. (in Bulgarian)
4. Boyd, C. E., C. W. Wood, T. Thunjai (2002) Aquaculture Pond Bottom Soil Quality Management. Pond Dynamics/Aquaculture Collaborative Research Support Program. Oregon State University, Corvallis, Oregon, USA, pp. 41.
5. Briggs, M. R. P. And S. J. Funge – Smith (1994) A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management*, 25: 789-811.
6. Hopkins, J. S., P. A. Sandifer, C. L. Browdy (1994) Sludge management in intensive pond culture and shrimp-effect of management regime on water quality, sludge characteristics, nitrogen extinction, and shrimp production, *Aquac. Eng.*, 13: 11–30.
7. Jamu, D. M. And R. H. Piedrahita (2001) Ten year simulations of organic matter concentrations in tropical aquaculture ponds using the multiple pools modelling approach. *Aquacult. Eng.* 25: 187–201.
8. Kajak, Z. (1995) Eutrofication of lowland reservoirs. – Environment Monitoring Library. pp. 33–41. Lordz, Poland.
9. Krom, M. D., C. Porter, H. Gordin (1985) Nutrient budget of a marine fish pond in Eilat, Israel, *Aquaculture* 51: 65–80.
- Kasza, H. (1995) Eutrofication symptoms vs. Ecological succession in Goczalkowice Reservoir. – Environment Monitoring Library. Pp. 143-153. Lodz, Poland.
10. Hadjinikolova L. And A. Stoeva (2007) Dynamics of nitrogen contents in water and sediments of carp ponds, Conf. Proceedings III Internat. Conf. “Fishery”, 1-3 February 2007, Belgrad, 135–140.
11. Hadjinikolova L. and D. Terziyski, 2011. Nutrient assessment of sediments of carp fish ponds, Conf. Proceedings V Internat. conf. “Aquaculture&Fishery”, 01 - 03 June, 2011, Belgrad, 389-395.
12. Terziyski D. and L. Hadjinikolova, 2012. Chemical composition of sediments from fish ponds as a natural biological product, *Agricultural Science and Technology* , 4 (1):36-40.
13. Straskraba, M., Tundisi, J. (1999) Guide lines of lake management. Volume 9: Reservoir water quality management. International Lake Environment Committee Foundation, Shiga, pp. 229.
14. Smith, P. T. (1996) Physical and chemical characteristics of sediment from prawn farms and mangrove habitats on the Clarence River, Australia, *Aquaculture*, 146: 47–83.