SPECTRAL ANALYSIS OF SOME SELECTED HYDROCHEMICAL PARAMETERS OF DIYALA RIVER IN IRAQ

Aqeel S. Al-Adili [1] and Qusay A. Al-Suhail [2]

[1] Dams and Water Engineering Branch, Dep. of Building and Construction Engineering, University of Technology, Iraq
E-mail: aqeeladili@hotmail.com
[2] Dept. of Geology, College of Science, University of Basra, Iraq
E-mail: quab65@yahoo.com

ABSTRACT

Some selected hydrochemical parameters of Diyala river including electrical conductivity (*EC*), $Ca^{+2}, Mg^{+2}, SO_4^{-2}, Cl^{-1}, HCO_3^{-1}$, total soluble solids (*T.S.S.)*, discharge (*Q*) and total hardness (*TH,*) were analyzed for their periodicities using monthly measurements for the period 1993-1997, to quantify and qualify surface water and investigate the periodicity behavior of these parameters. Results showed significant autocorrelation for all the studied series and therefore they were subjected to the Spectral (Fourier) analysis to investigate the main periodicities that contribute to the total variance of the observed data. Most of the selected parameters have strong (less frequent) semi-annual and biannual cycle, as well as seasonal cycle for, C*l, Mg, Ca,* SO_4, HCO_3, *TSS*, and *EC*. These results reveal the variation of the factors affecting the river water quality including hydrological and meteorological conditions as well as the impact of human activities through the river catchments area.

Keywords: Periodicities, Spectral (Fourier) Analysis, Harmonic analysis, Autocorrelation

1. INTRODUCTION

Diyala River is one of the main water resources of Iraq and one of the most important tributaries of Tigris River in Iraq. For this reason many cities are situated on its banks, as well as, wastes fluids of agricultural and industrial activities in these cities are also concentrated directly to this river. It drains an area of about 32600 km^2 lying across Iraqi-Iranian frontiers. The river basin is widely varied through the entire catchments area from semi-arid plain north of Baghdad to mountainous area of western Iran, (Al-Ansari and Al-Jabbari, 1987). The river catchments were divided into four parts; above Derbendikhan, Upper Diyala, Middle Diyala and Lower Diyala, each of these have different characteristics and different contribution to the main river flow. From geological view point, river catchments have different geological units; above Derbendikhan the catchments lies within thrust zone and the exposed rocks are of Jurassic age, whereas the Upper and Middle Diyala lie within the folded zone in which the cretaceous strata are exposed, as well as Mukdadiya, Fatha formations and

Quaternary terraces are dispersed. Lower Diyala is covered mainly by recent alluvium and lies within the unfolded zone (Al-Ansari et al., 1987a).

The Climatic conditions vary so much in the river catchments in which the rainy season starting from November to April, the annual amount of precipitation varies from 800 mm near the northern parts to 250 mm near southern limits of the basin. The annual evaporation rate may reach as high as 2000 mm/year (Al-Jiboury, 1991). These conditions have clear effects on alteration of wet and dry years and then on the variation of river water quality. However, the catchments area of Diyala river are lies within highly cultivated regions and have many canals and drainage channels, which contributing and affects river hydrochemistry and made variation of most of cations and anions, and this will effect on Diyala river as controlled river.

Many hydrochemical studies were achieved showing that water chemistry of the river is varied both spatially and temporally for the upstream river side. Al-Ansari et al., 1987b; Al-Sinawi, 1986; and Al-Adili, 1992, are among others.

The main objective of the study is to quantify and qualify surface water as well as investigate the periodicity behavior of some selected parameters of Diyala River, using spectral (Fourier) analysis, linear regression, harmonic analysis, depending upon the monthly measurements for the period 1993-1997 available from the state of irrigation projects operation and maintenance. These include electrical conductivity (*EC*), Ca^{+2}, Mg^{+2}, SO_4^{-2}, Cl^{-1}, HCO_3^{-1}, total soluble solids (*T.S.S.*), total hardness (*TH*) and discharge (*Q*), (Table 1). Though discharge have less recording period (25 records) but, its importance for comparison purposes with the used parameters, reviles it's inclusion in the analysis.

2. METHODOLOGY

Autocorrelation:

Autocorrelation can be defined as the measure of time dependence of a given time series for different lags. The values of autocorrelation coefficient for different lags and given confidence limits could be schematically shown using correlogram which indicates series trend and periodicity. Serial autocorrelation take the following form (Fuller, 1976):

$$r_L = \frac{Cov\left|Y_i + Y(i+L)\right|}{\left[VarY_i * VarY(i+L)\right]^{\frac{1}{2}}} \tag{1}$$

It can also be expressed using serial covariance as:

$$r_L = \frac{Serial\ Cov(C_L)}{Serial\ Cov\ at\ Lag(C_0)} \tag{2}$$

where Y = *average*; $0 < L < N$; L = lag (represents the shift between any two compared series).

Spectral Analysis:

Spectral (Fourier) analysis is used for describing the structure of time series and explains the main components that contribute to the total variance in the observed data and defining the behavior using spectral density function. This function is the Fourier transform of the serial covariance as: (Fuller, 1976);

$$\gamma(L) = \int e^{itw} df(w) \tag{3}$$

For continuous series:

$$\gamma(L) = \int e^{itw} f(w) dw \tag{4}$$

where

$\gamma(L)$ = variance at lag L,
$f(w)$ = spectral density distribution function,
w = angular frequency,
t = time,
$i = \sqrt{-1}$

Fourier transform is the method of transforming any function in term of time $Y(t)$ to another function in term of frequency $f(w)$, where the latter function gives independent values with different frequencies as compared with time function which are strongly correlated leading to interpretation difficulties.

3. RESULTS AND DISCUSSION

Monthly readings of the selected parameters were plotted to define their trends, Figures 1 to 3. As revealed by these figures, Discharge *(Q)*, *Mg*, and HCO_3 parameters shows noticeable increasing trend more than *T.H.* and *Cl* While *T.S.S.* and *EC* have slight decrease trends as compared with SO_4 and *Ca*. Significant trends have clear effect on the analysis of time series especially if these series were taken on the basis of shorter period and less frequent sampling (Feng et al., 2004). Accordingly they should be removed before carrying out the spectral analysis.

The average flow during the studied period reaches 160 m^3/day, Table 1. Generally, the flow increase with time, and most of discharge values fluctuated close to the mean, this is due to the effect of water flow regulation by dams (Al-Ansari et al., 1987a). However, the average monthly discharge showed that the maximum monthly flow of Diyala River occurs during February (Fig. 4).It should be consider here, that the flow of Diyala River is controlled by the Hemrin Dam along the year.

Correlogram of 95% confidence limit of the studied hydrochemical parameters Figures 5 to 7, shows clear periodicities (cycles), but they differ in their amplitude of the main components that contribute to the total variance of the observed data. Periodogram of the above parameters can be used to examine the main periodicities and their frequencies. According to the periodograms of the current data as depicted in Figures 8 to 10, it is clear that there exist significant differences among the appeared periodicities. These periodicities can be classified as: strong clear (less frequent), clear, and moderately clear (more frequent). Concerning *EC*, biannual cycle (5.1 months) and the cycle of 15.3 months which can called as " semi-annual " cycle are the most clear, (Table 2), (Fig. 4-a). Other ions and total dissolved solids have strong clear semi-annual cycle but with less frequent occurrence. But *Ca, Mg,* SO_4*, Cl*, and *TSS* have clear biannual cycle, as well as, seasonal cycle for *Ca, Mg,* SO_4*, Cl*, HCO_3, *TSS*, and *EC*. However, discharge (*Q*) clearly shows seasonal periodicity, the seasonal periodicity was confirmed by spectral analysis (Fig.8-d), and more frequent double annual cycles. This result is a reflection of both natural flow and meteorological conditions within the basin. As with regards to total hardness (*TH*) have an annual periodicity (11.5 months) as well as, biannual and seasonal but with moderately clear.

Most likely, the biannual cycle reflects the effect of time lag between the rainy and snow melt periods in the upper parts of the river catchments. Seasonal cycle reflects the impact of meteorological conditions on flow behavior whereas the semi-annual cycle exhibits the effect the overall natural conditions plus discharges release control through the dams installed upstream.

According to the aforementioned results there are significant variations in the periodicities of the studied parameters, however, it should be stressed here that the current results are restricted for the study period only and the real behavior of the river may be more clear if the measurements were taken for longer periods on the weekly or daily basis, (Al-Ansari et al., 1987b).

4. CONCLUSIONS

1. Slight increasing trends in the studied hydrochemical parameters were noticed for *Q, Mg*, *T.H.*, *Cl* and HCO_3, while *T.S.S.*, SO_4, *Ca* and *EC* have slight decreasing, and high autocorrelation of the analyzed series were observed indicating existence of different periodicities.
2. The study showed that the highest average monthly discharge for Diyala River is within February.

3. Semi-annual, biannual and seasonal cycles were found to be the most prominent periodicities contributing to the total variance of the most analyzed data. This reflects effects of the contributions for widely range of canals and drainage channels within the river basin.
4. Semi-annual cycle reflects the effect of wet and dry years' fluctuation plus man made impact, whereas the biannual and seasonal cycles indicate the impact of flow and meteorological conditions throughout the entire river catchments area.
5. Measurements for Diyala River after 10 or 15 years from this date recordings will be very useful and effective to compare and evaluate this study results.

REFERENCES

[1] Al-Adili, A.; 1992, Effect of human activities on water quality of Lower Diyala river, Unpub. M Sc. Thesis, Univ. of Baghdad, 108 p.

[2] Al-Ansari, N. and Al-Jabbari, M.; 1987, Hemrin reservoir, geological and hydrological investigation, J. of Water Res., Special Publ. No. 2, Sector 2.

[3] Al-Ansari, N., Al-Jabbari, M. and Al-Shakiri, A.; 1987a, Reservoir, geological and hydrological investigation, J. of Water Res., Special publ. No.2, Sector 3.

[4] Al-Ansari, N, Salman, H.H., Al-Sinawi, G.T.; 1987b, Periodicity of selected Water quality parameters for the Tigris Water at Baghdad, Jour. of Water Resources, Vol. 6, No. 2, pp. 40-66.

[5] Al-Jiboury, T.H.; 1991, Hydrology and geomorphology of Diyala River, Unpub. Ph.D. thesis, Univ. of Baghdad, 238p.

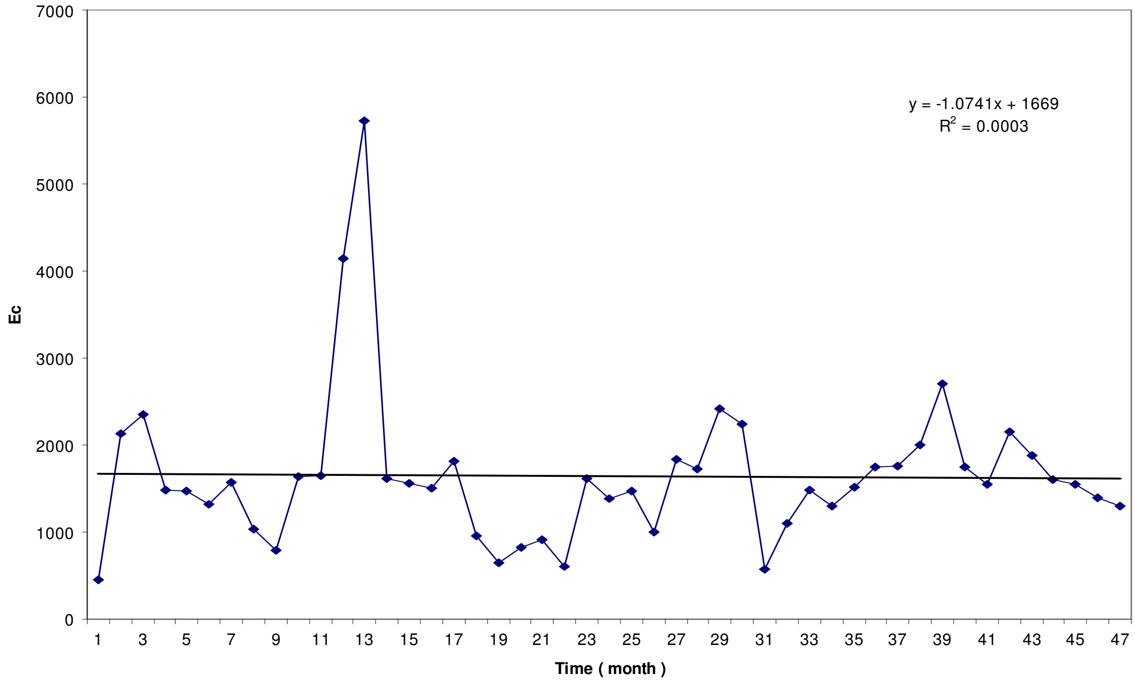
[6] Al-Sinawi, G.T.; 1985, Hydrochemistry and hydrology of Lower Diyala river, Unpub. M.Sc. thesis, Univ. of Baghdad., 212p.

[7] Feng, X., Krichner, J. and C. Neal; 2004, Spectral analyses of chemical time series from long-term catchment monitoring studies: hydrochemical insight and data requirements. Water, Air and Soil Pollution, Vol. 4, pp. 221-235.

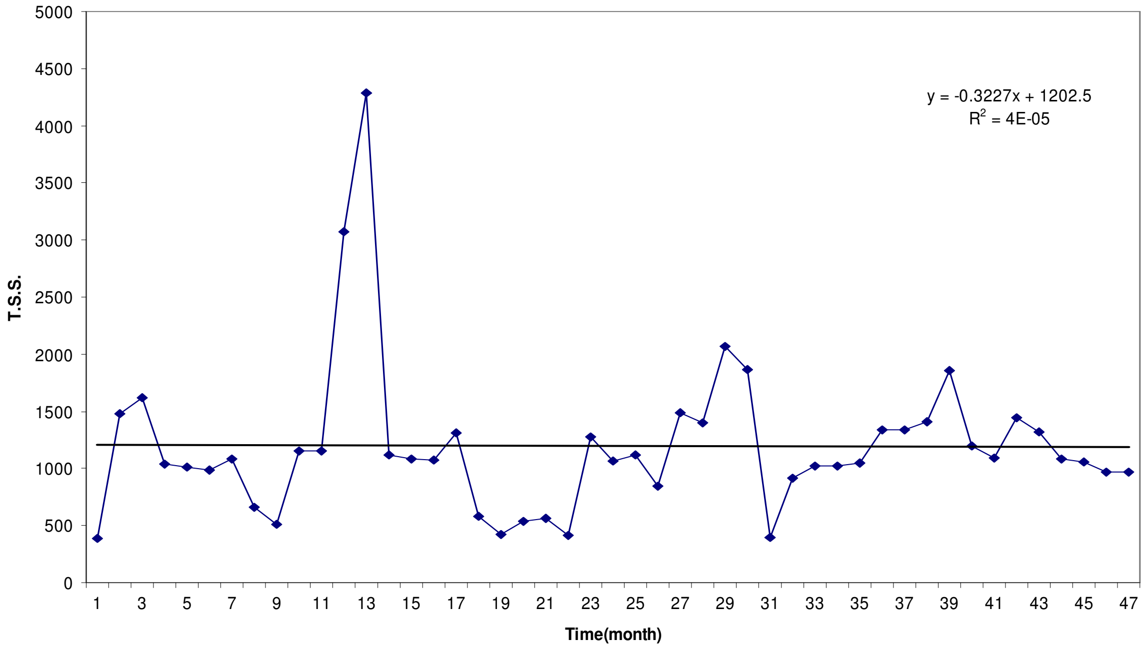
[8] Fuller, A.; 1976, Introduction to statistical time series, John Wiley Inc.

Table 1: The results of analysis for Diyala river at Baquba station

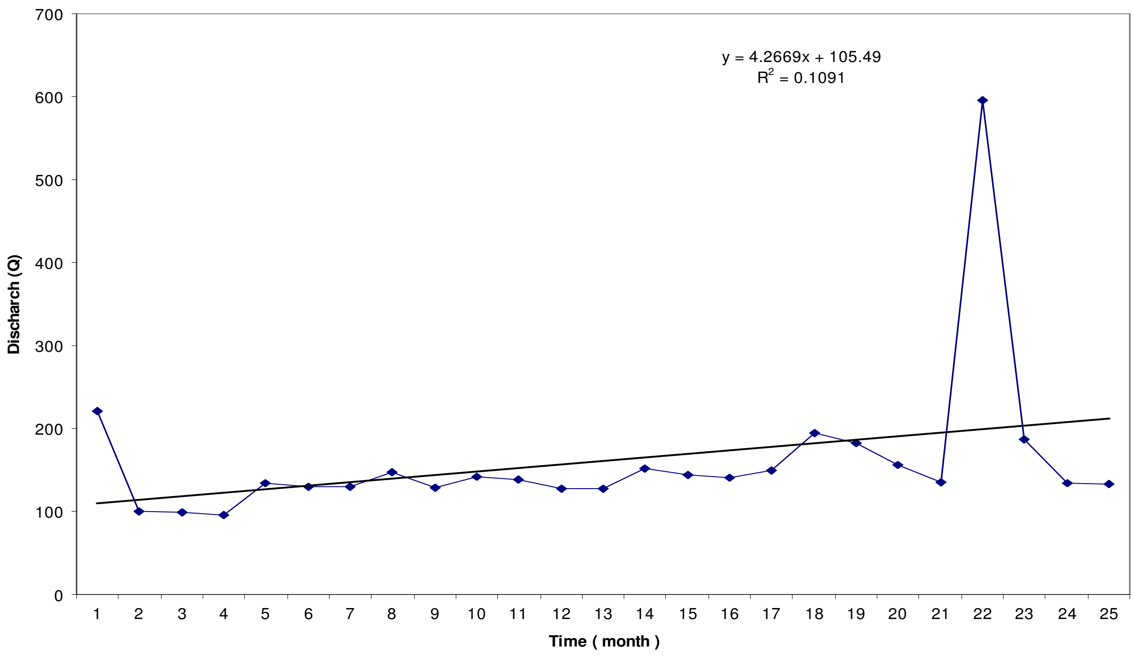
Samples	EC $*10^6$	T.S.S (ppm)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	T.H. (mg/l)	HCO_3 (mg/l)	Q (m^3/day)
1	451	386	40	27	58	96	187	80	221
2	2130	1476	176	29	276	768	554	274	100
3	2350	1624	108	116	276	574	630	255	99
4	1480	1040	112	34	158	442	476	176	96
5	1470	1008	106	29	144	432	462	176	134
6	1320	990	104	29	152	371	436	116	130
7	1570	1086	112	43	168	448	479	188	130
8	1038	664	54	28	136	265	284	128	147
9	796	509	38	32	87	214	151	80	129
10	1640	1152	124	56	181	464	512	196	142
11	1650	1152	124	56	175	462	468	196	139
12	4140	3072	358	192	683	1105	1136	288	127
13	5720	4290	417	258	832	1588	1379	320	127
14	1610	1120	118	46	175	456	508	196	152
15	1560	1080	106	44	165	424	400	176	144
16	1510	1072	102	38	165	417	383	176	141
17	1810	1316	188	76	214	493	633	240	149
18	961	584	62	24	85	216	224	96	194
19	653	424	40	21	68	128	174	80	182
20	820	536	54	22	76	186	209	96	156
21	908	564	58	24	76	208	219	96	135
22	606	412	34	17	49	110	158	80	596
23	1610	1280	122	48	188	385	429	176	187
24	1390	1064	116	42	176	346	388	157	134
25	1470	1120	119	46	184	354	412	176	133
26	1001	846	76	38	132	245	327	137	----
27	1830	1488	153	76	216	497	596	213	----
28	1720	1400	149	72	202	476	556	196	----
29	2420	2068	288	115	486	576	943	248	----
30	2240	1864	248	91	452	568	852	248	----
31	571	398	54	29	88	116	256	131	----
32	1095	912	80	53	162	274	420	145	----
33	1480	1025	104	59	163	400	504	119	----
34	1300	1020	107	56	138	299	500	217	----
35	1520	1045	102	76	174	423	570	175	----
36	1750	1335	114	76	217	442	599	630	----
37	1760	1338	115	74	217	445	596	135	----
38	2000	1410	124	67	272	453	589	145	----
39	2700	1860	141	117	437	654	840	205	----
40	1750	1195	112	70	215	457	570	181	----
41	1550	1095	88	62	184	366	480	173	----
42	2150	1440	76	106	277	474	183	----	----
43	1880	1320	116	84	198	505	640	----	----
44	1600	1085	94	79	181	426	565	----	----
45	1550	1055	88	82	190	363	560	----	----
46	1400	965	102	70	175	325	545	----	----
47	1300	970	94	61	200	269	491	----	----
Mean	1643	1194	119	63.6	211	425	499	183	160


y = -1.0741x + 1669
R^2 = 0.0003
Ec
Time (month)

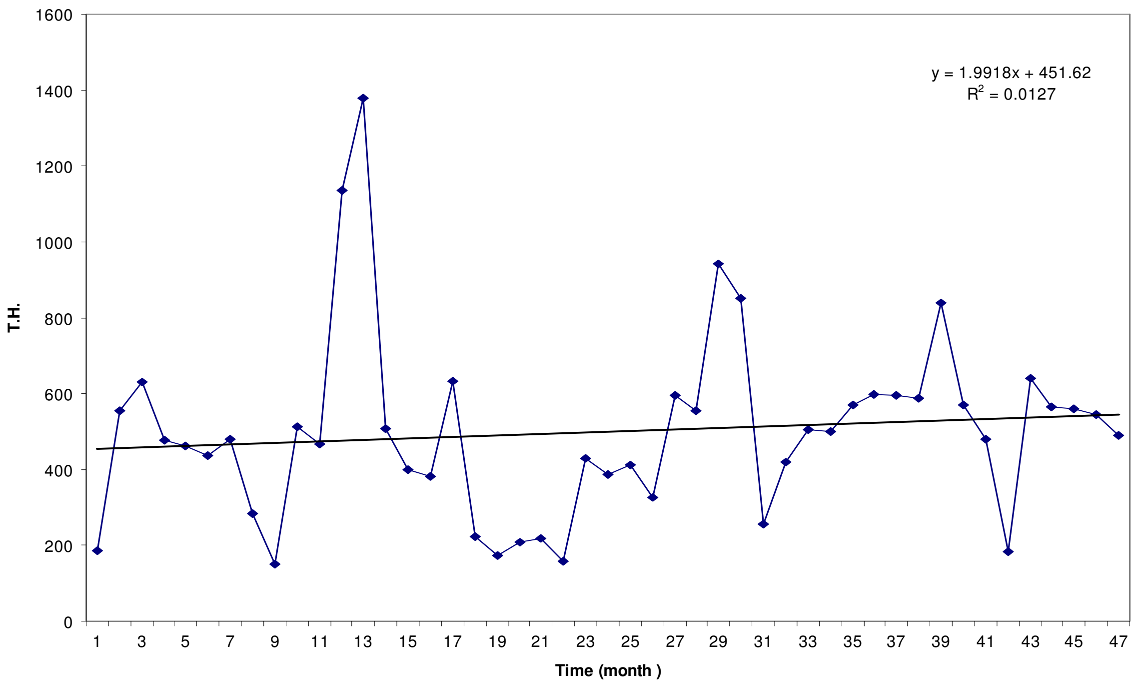
(a)


y = -0.3227x + 1202.5
R^2 = 4E-05
T.S.S.
Time(month)

(b)



(c)

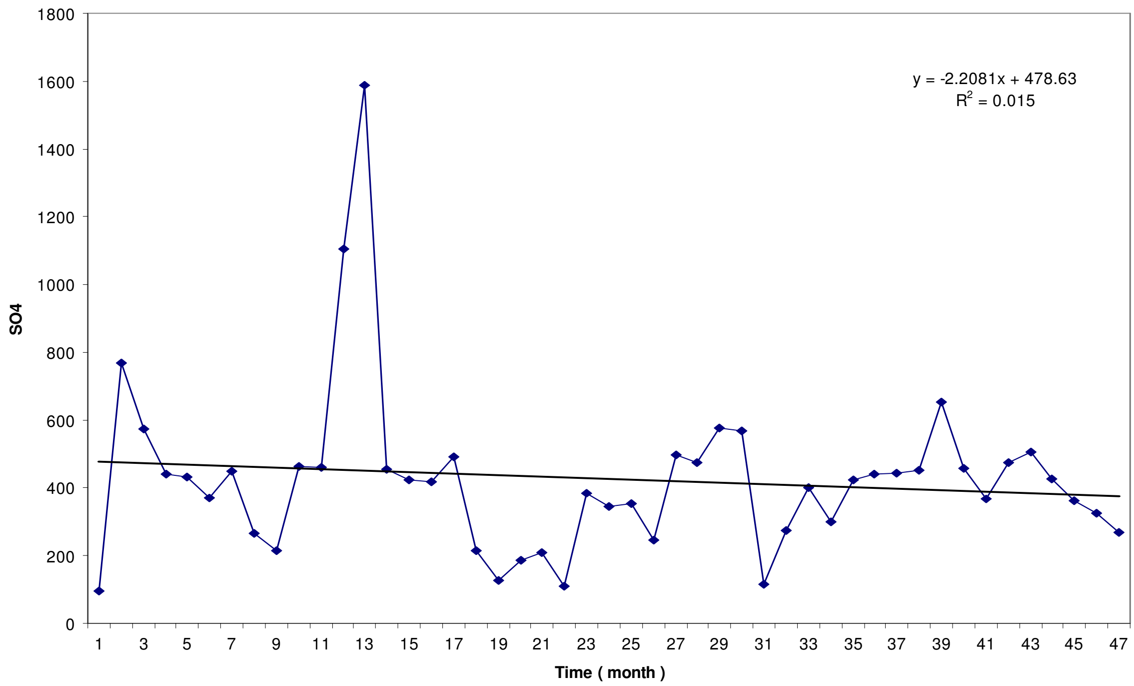


(d)

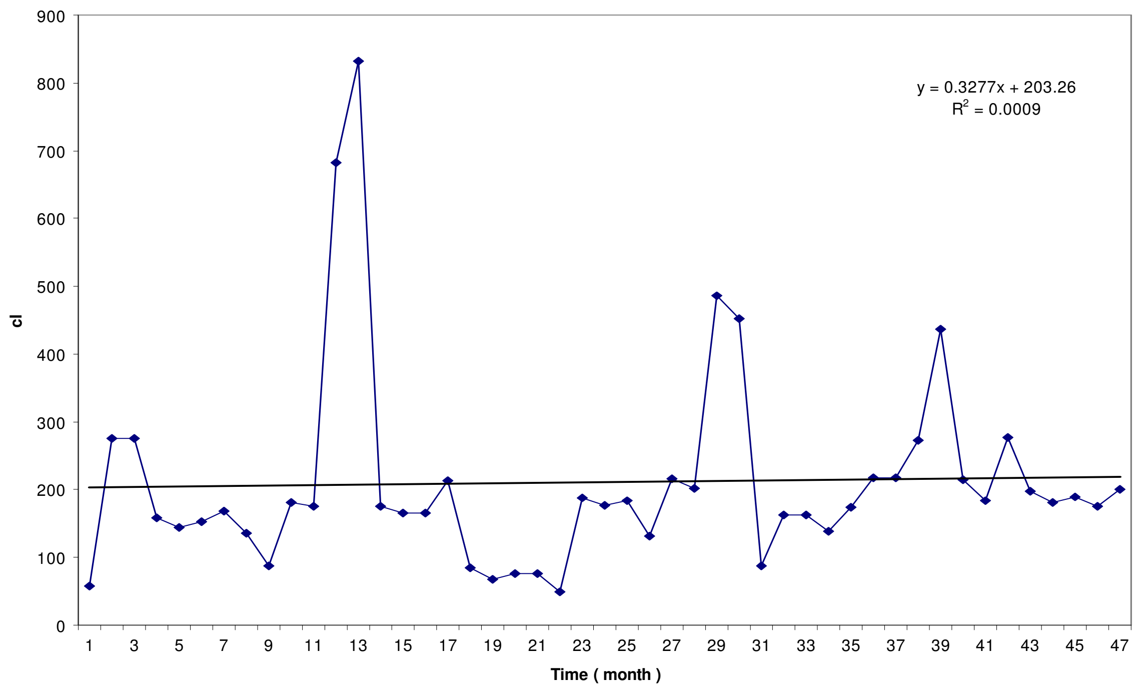
Fig. 1: Variation of EC (a), T.S.S. (b), Q (c), and T.H. (d) with time of Diyala River

Table 2: The variables of Diyala River periodicities

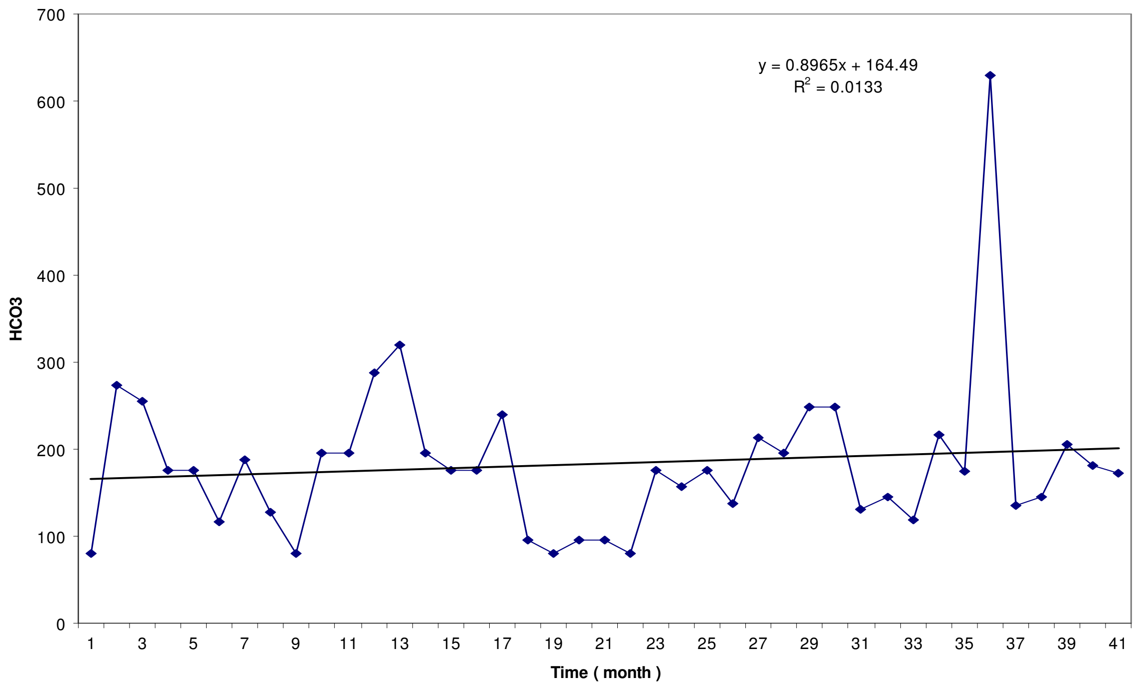
Variables	Frequencies	Periods (months)	Periodicities
EC	0.065 0.195 0.32	15.3 5.12 3.2	Semi-annual Biannual Seasonal
T.S.S.	0.065 0.195 0.32	15.3 5.12 3.2	Semi-annual Biannual Seasonal
Ca	0.042 0.17 0.33	15.3 5.12 3.2	Semi-annual Biannual Seasonal
Mg	0.065 0.195 0.32	15.3 5.12 3.2	Semi-annual Biannual Seasonal
cl	0.065 0.195 0.32	15.3 5.12 3.2	Semi-annual Biannual Seasonal
SO_4	0.065 0.195 0.32	15.3 5.12 3.2	Semi-annual Biannual Seasonal
T.H.	0.085 0.195 0.32	11.5 5.12 3.2	Semi-annual Biannual Seasonal
HCO_3	0.125 0.32	8 3.3	Semi-annual Seasonal
Q	0.04 0.29	24 3.4	Double annual Seasonal



(a)

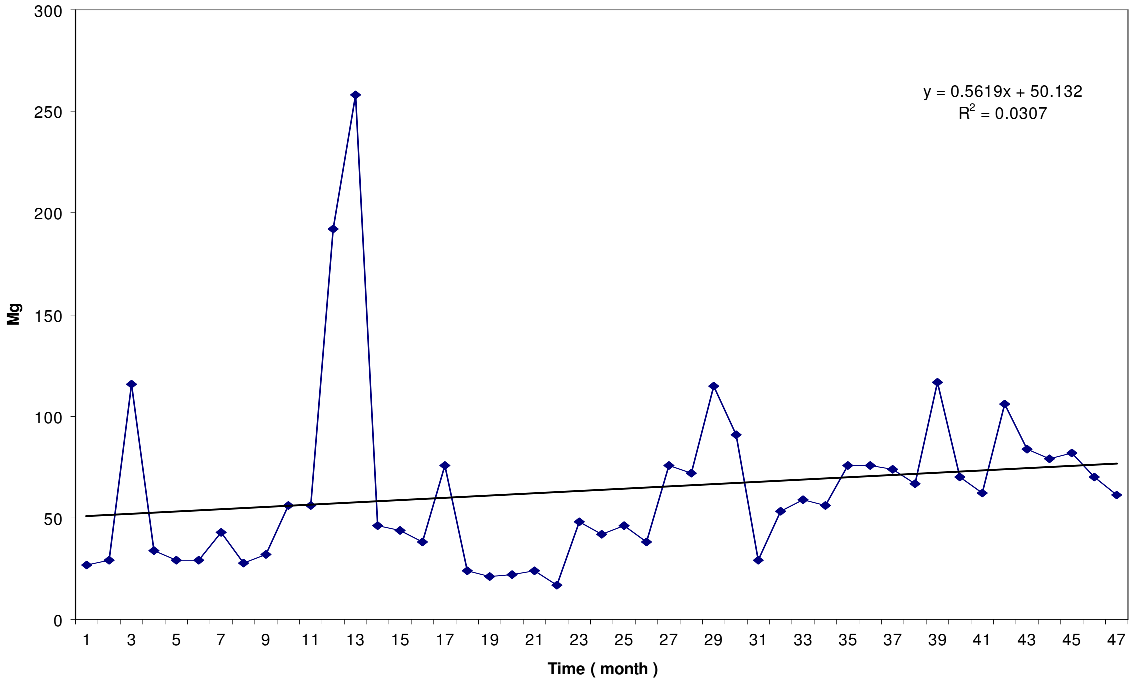


(b)

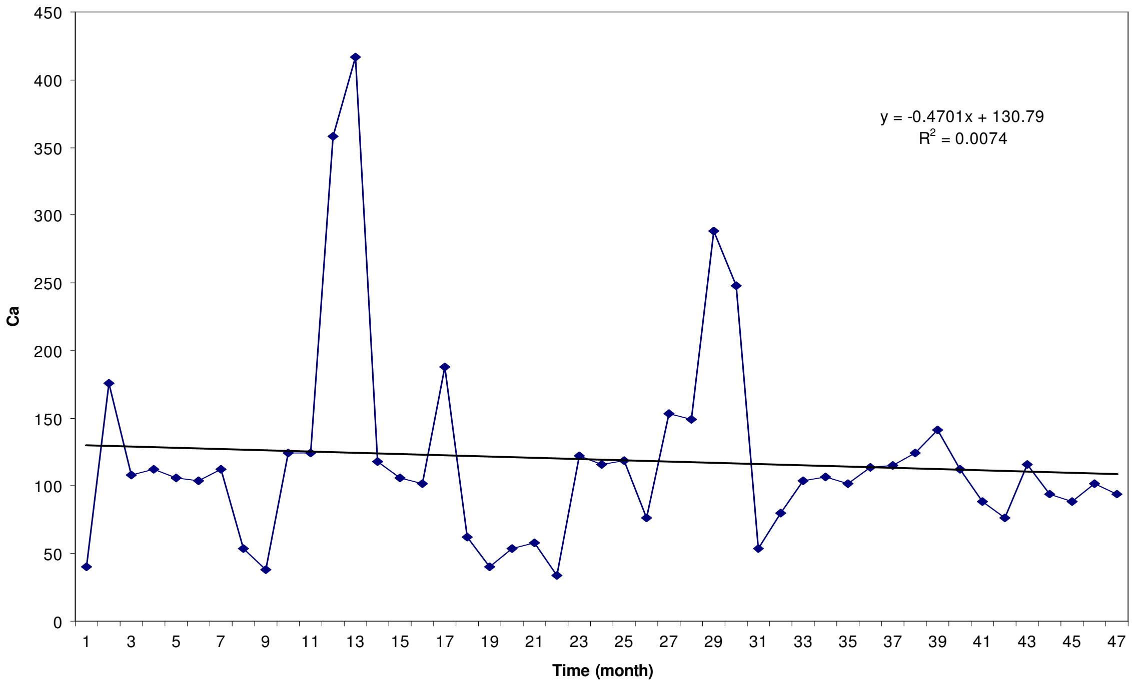


(c)

Fig. 2: Variation of SO_4 (a), cl (b), and HCO_3 (c) with time of Diyala River



(a)



(b)

Fig. 3: Variation of Mg (a), and Ca (b) with time of Diyala River

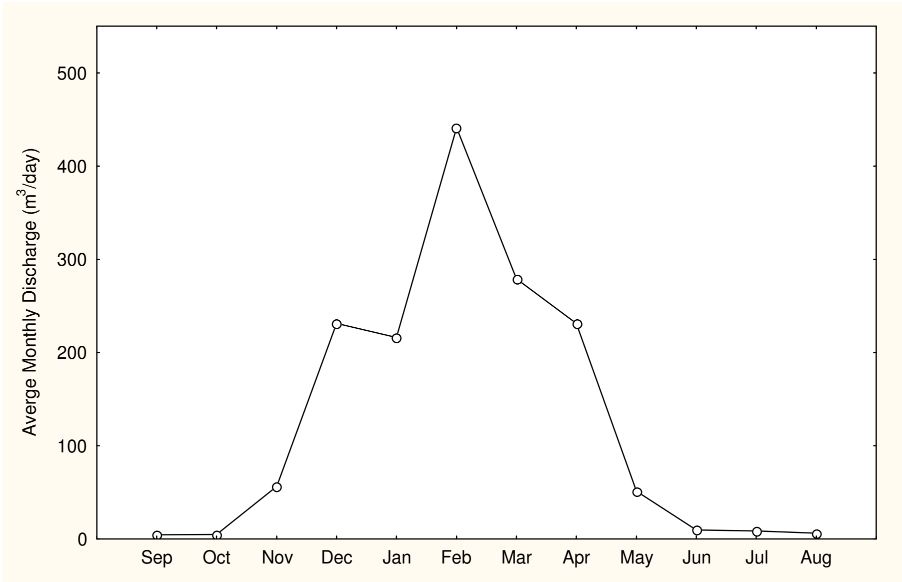
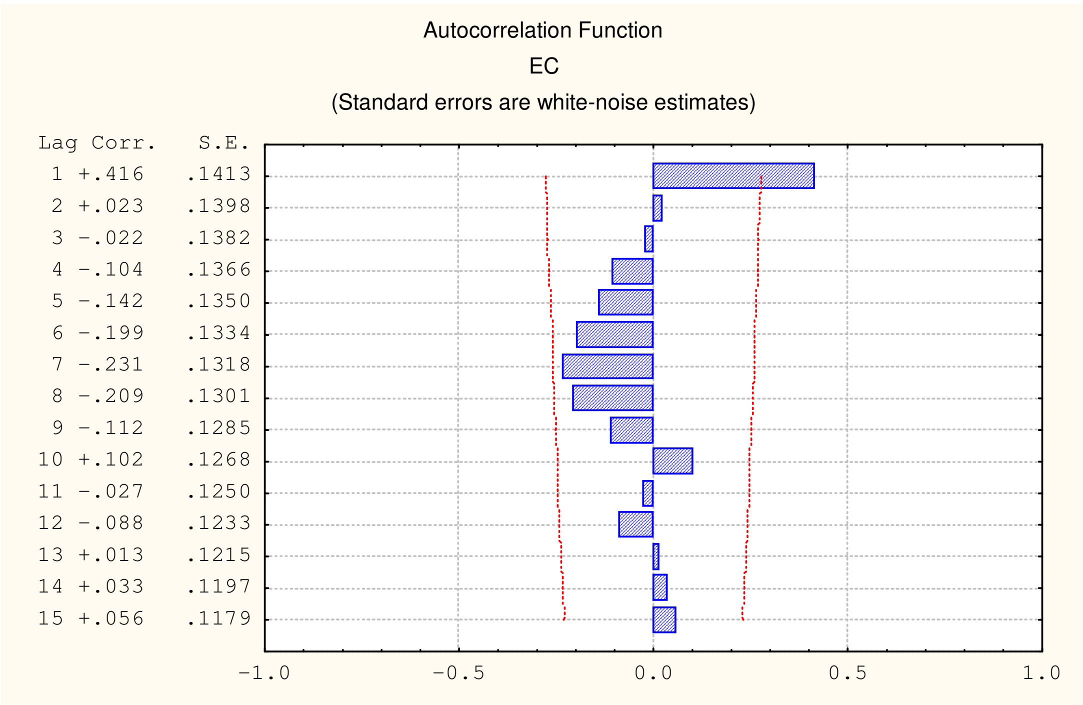
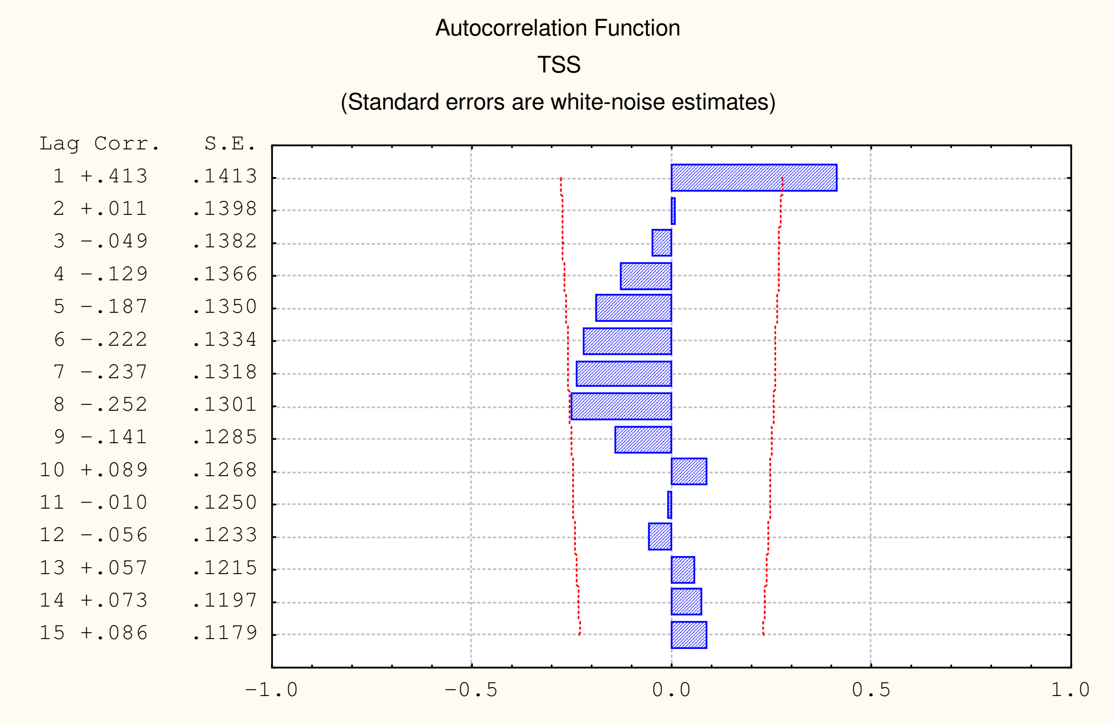


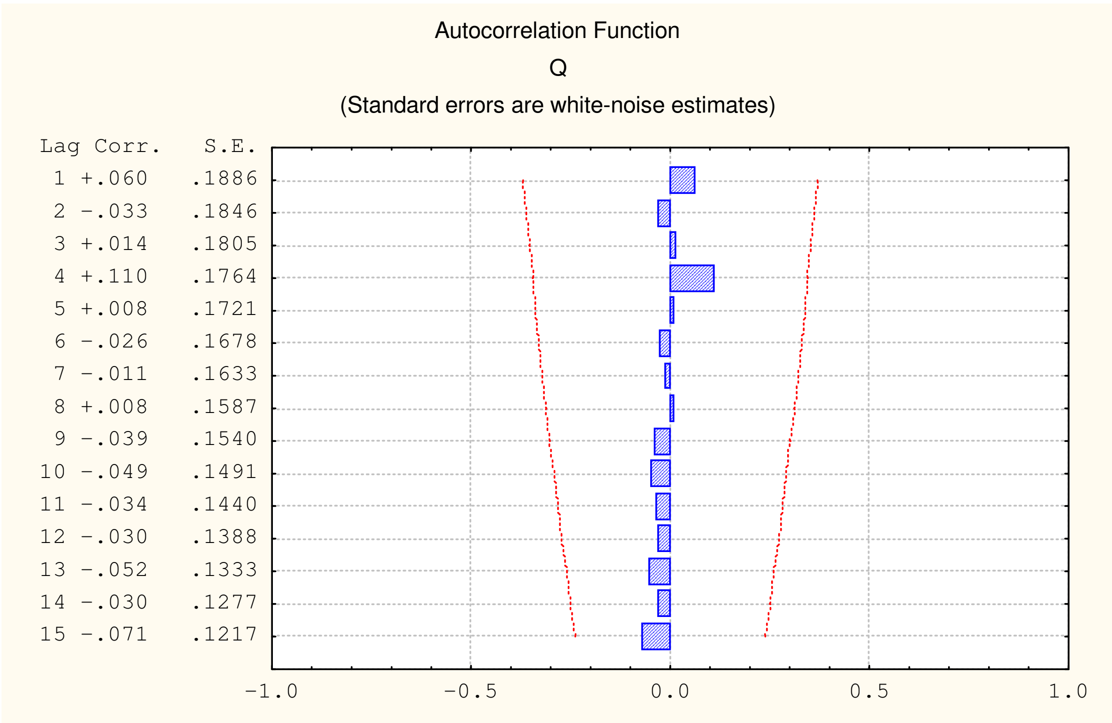
Fig. 4: Flow Hydrograph of Diyala River at Baquba from 1993 to 1997



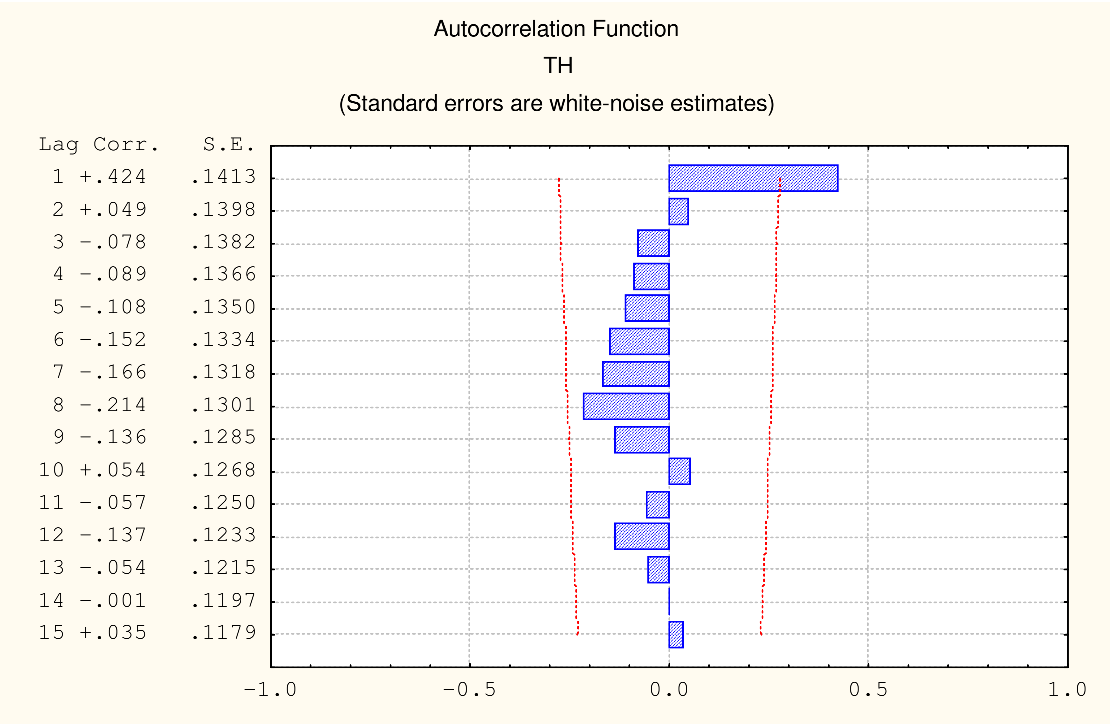
(a)


Autocorrelation Function
TSS
(Standard errors are white-noise estimates)
Lag Corr. S.E.
1 +.413 .1413
2 +.011 .1398
3 -.049 .1382
4 -.129 .1366
5 -.187 .1350
6 -.222 .1334
7 -.237 .1318
8 -.252 .1301
9 -.141 .1285
10 +.089 .1268
11 -.010 .1250
12 -.056 .1233
13 +.057 .1215
14 +.073 .1197
15 +.086 .1179
-1.0
-0.5
0.0
0.5
1.0

(b)

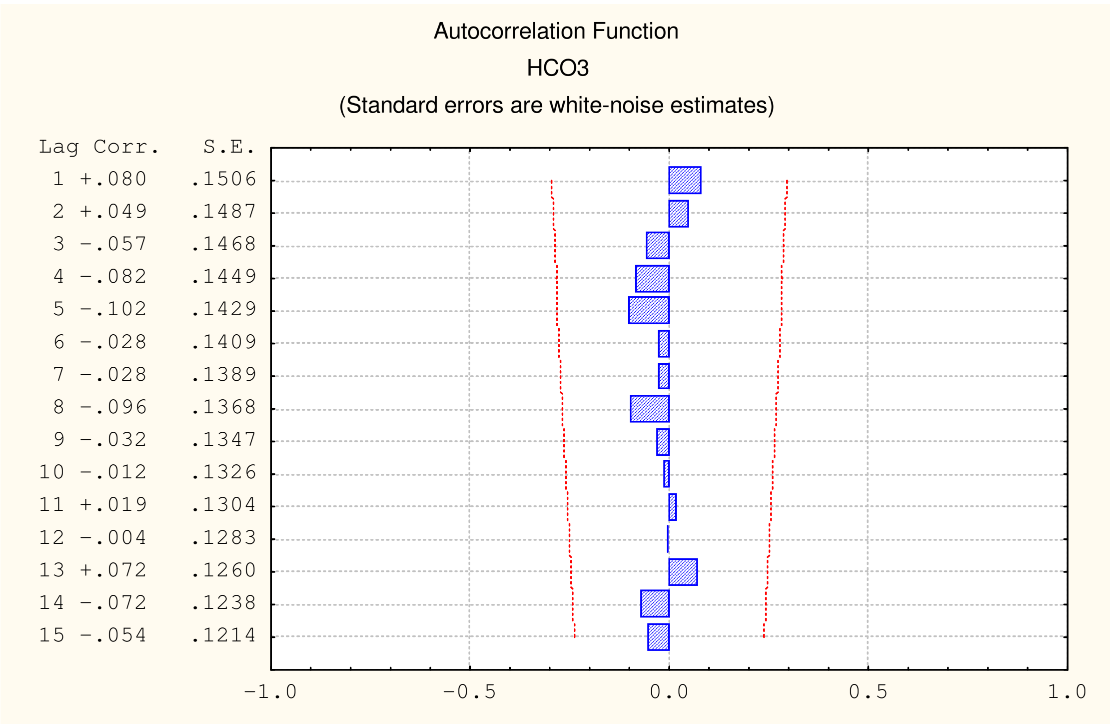

Autocorrelation Function
Q
(Standard errors are white-noise estimates)
Lag Corr. S.E.
1 +.060 .1886
2 -.033 .1846
3 +.014 .1805
4 +.110 .1764
5 +.008 .1721
6 -.026 .1678
7 -.011 .1633
8 +.008 .1587
9 -.039 .1540
10 -.049 .1491
11 -.034 .1440
12 -.030 .1388
13 -.052 .1333
14 -.030 .1277
15 -.071 .1217
-1.0
-0.5
0.0
0.5
1.0

(c)

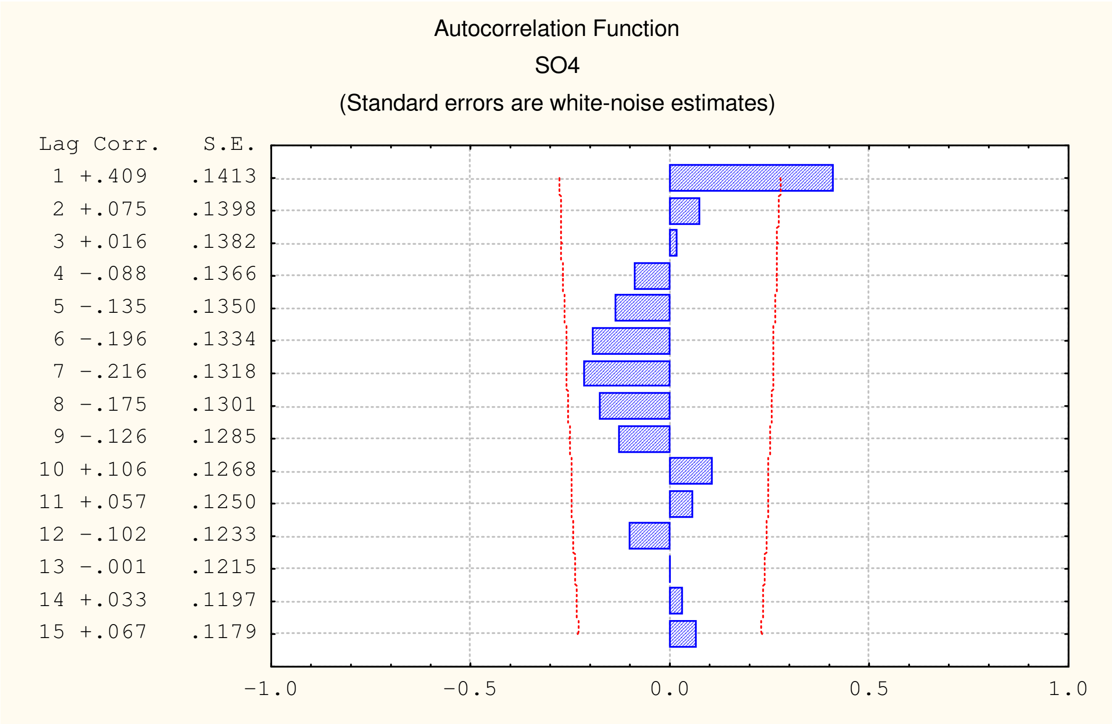


(d)

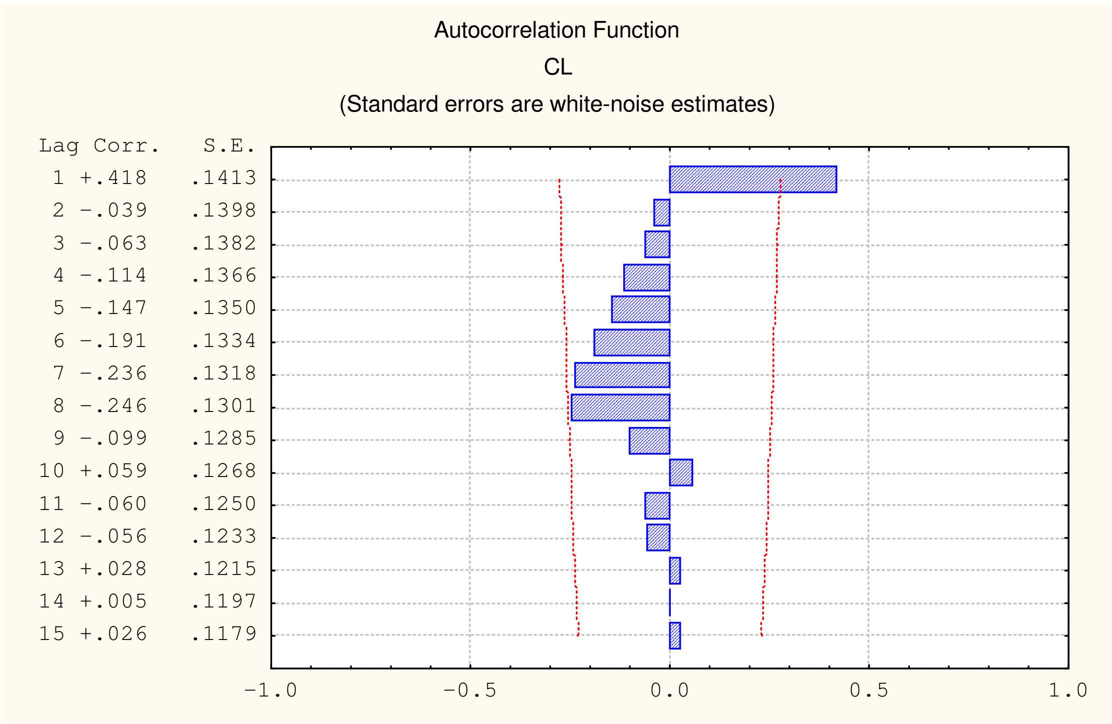
Fig. 5: Correlogram (95% confidence limit) of EC (a) and TSS (b), Q (c), and TH (d) of Diyala River



(a)

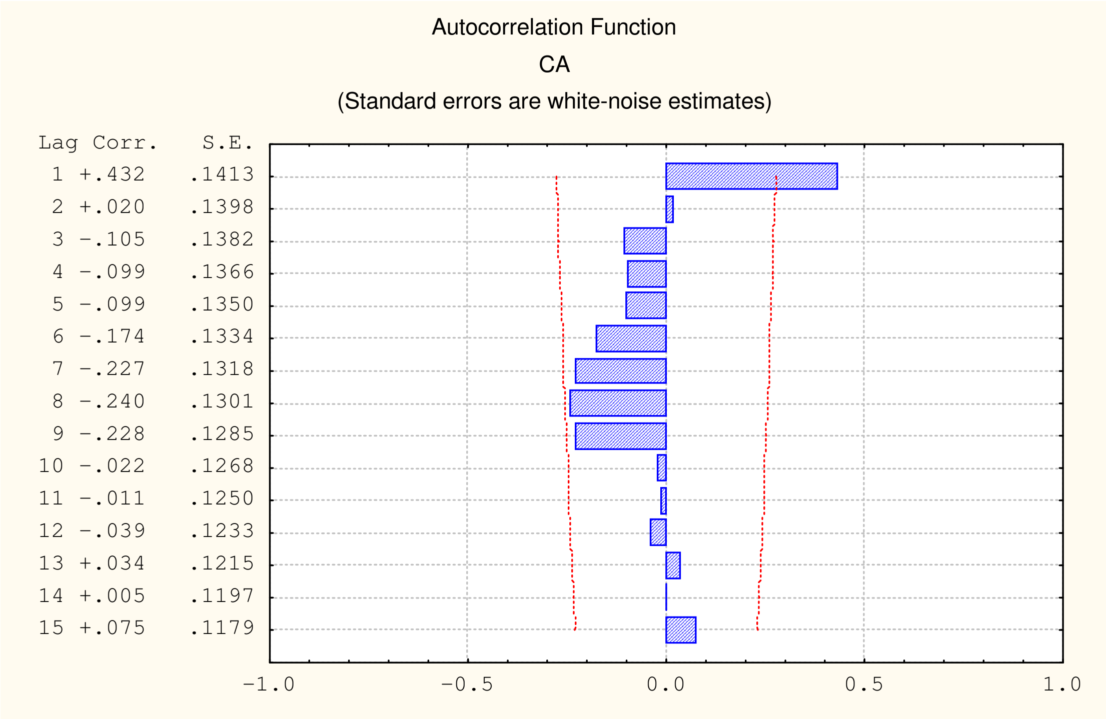


(b)

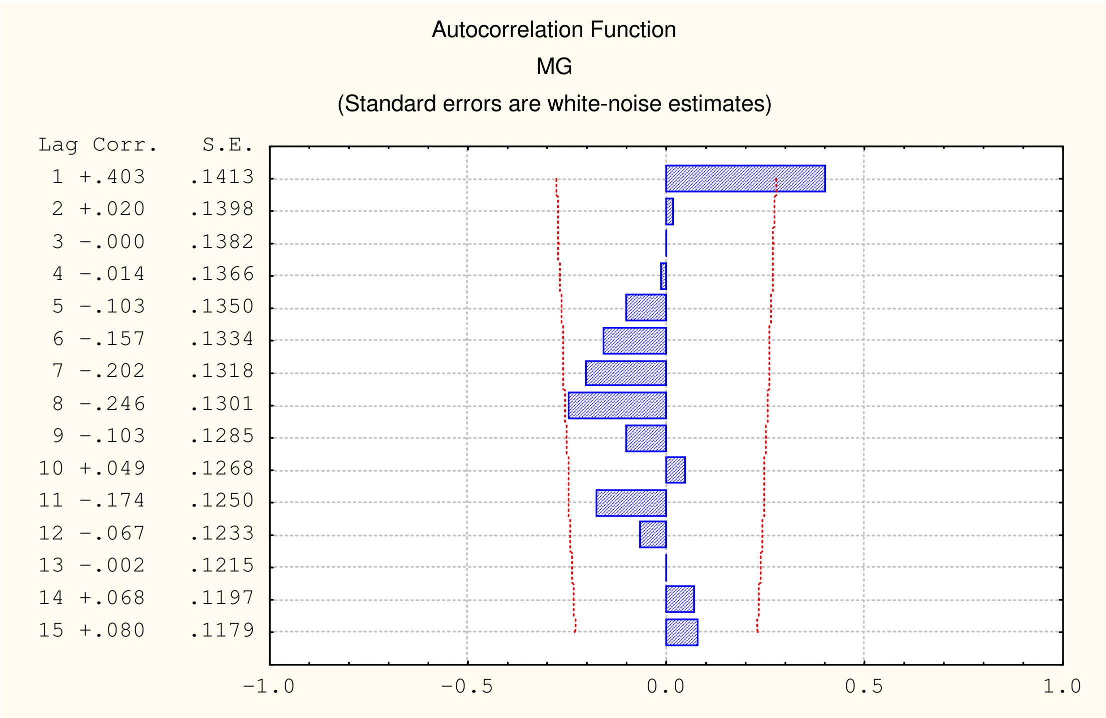


(c)

Fig. 6: Correlogram (95% confidence limit) of HCO_3 (a) and SO_4 (b), and cl (c) of Diyala River

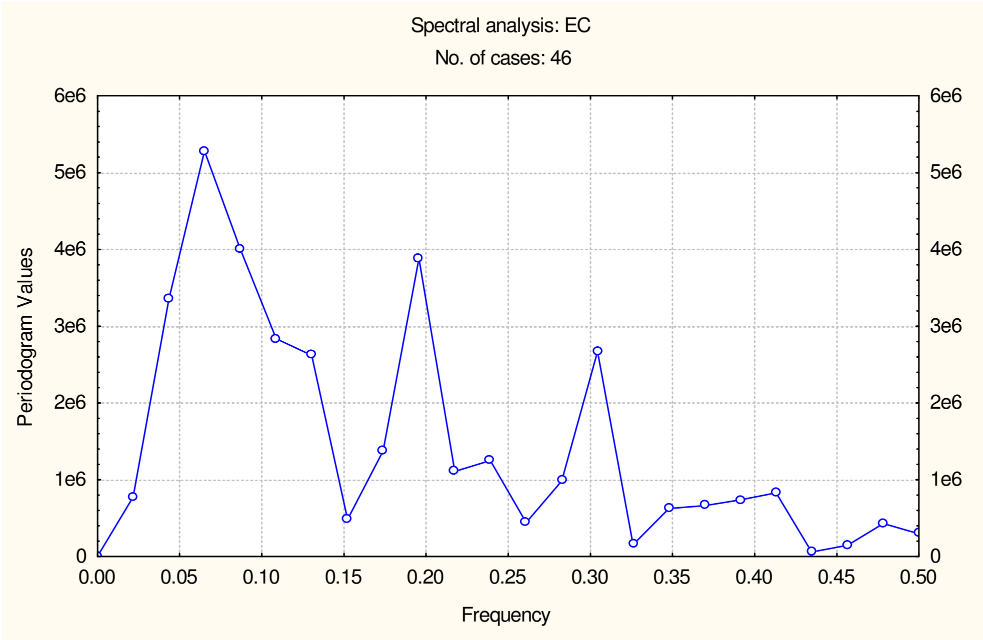


(a)

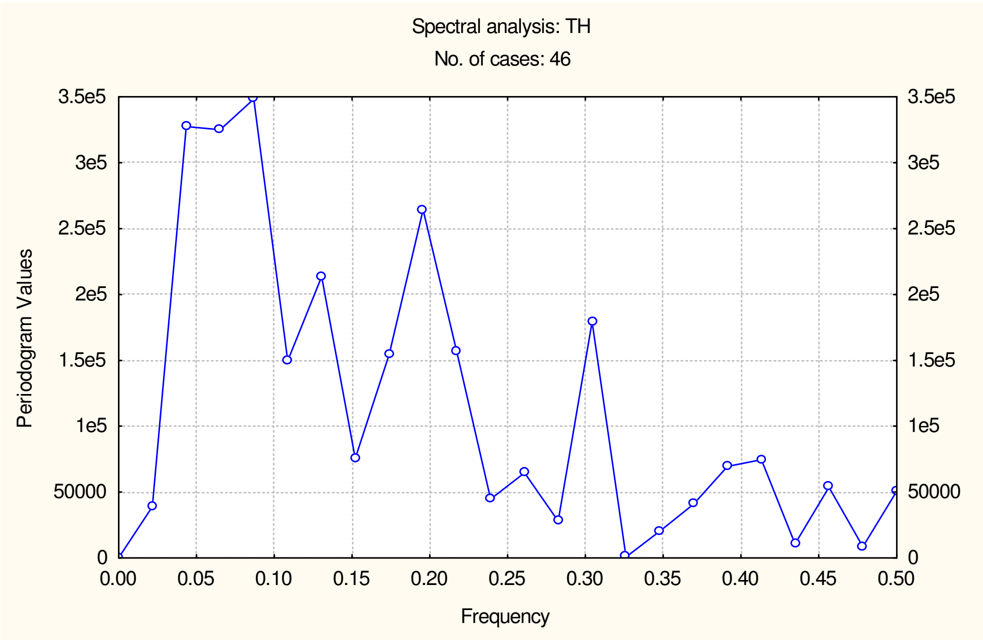


(b)

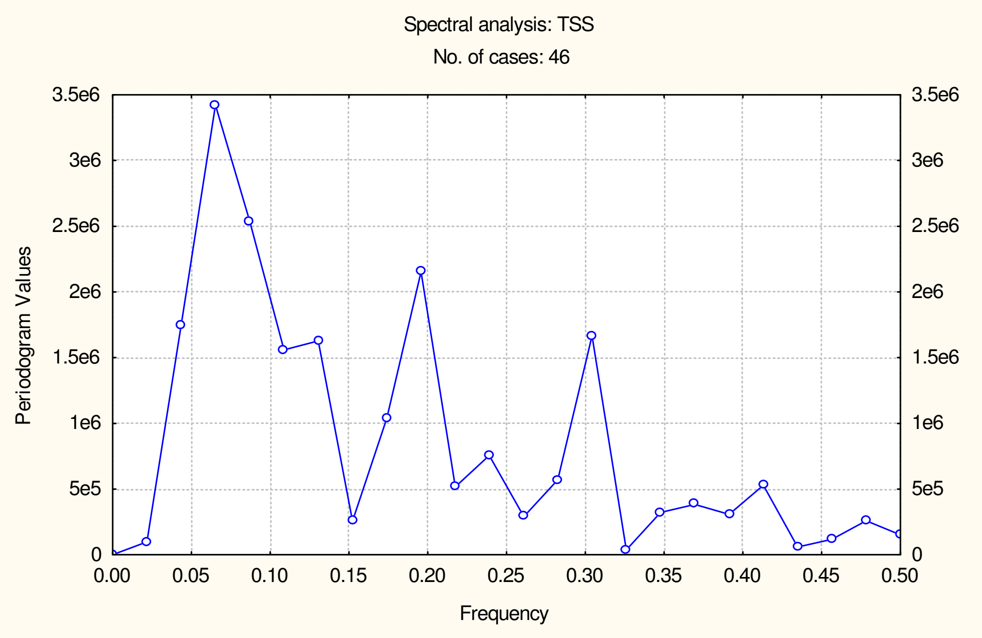
Fig. 7: Correlogram (95% confidence limit) of Ca (a) and Mg (b) of Diyala River


Spectral analysis: EC
No. of cases: 46
Periodogram Values
Frequency
6e6
5e6
4e6
3e6
2e6
1e6
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

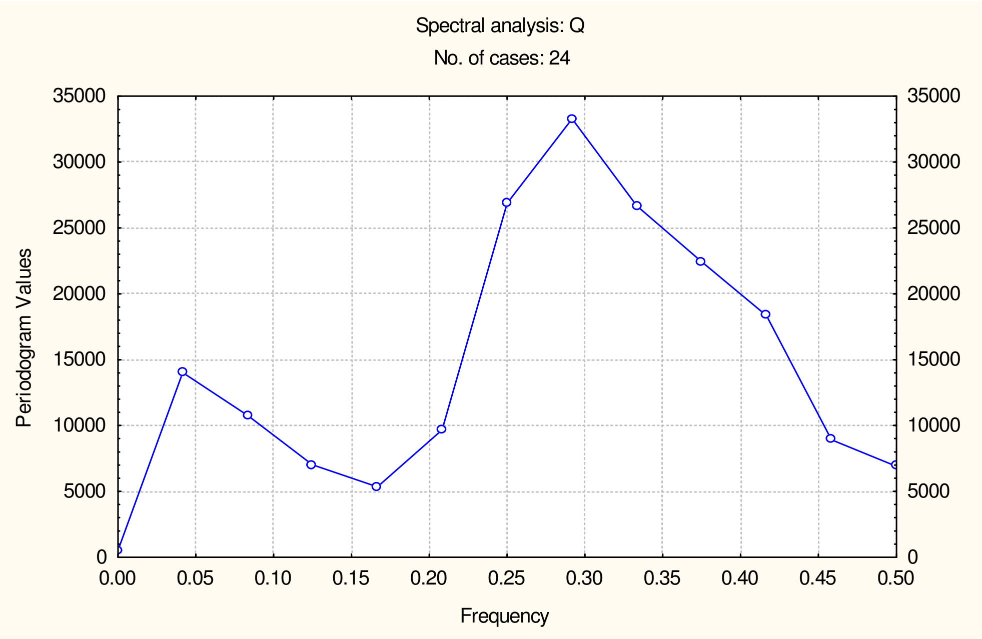
(a)


Spectral analysis: TH
No. of cases: 46
Periodogram Values
Frequency
3.5e5
3e5
2.5e5
2e5
1.5e5
1e5
50000
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

(b)

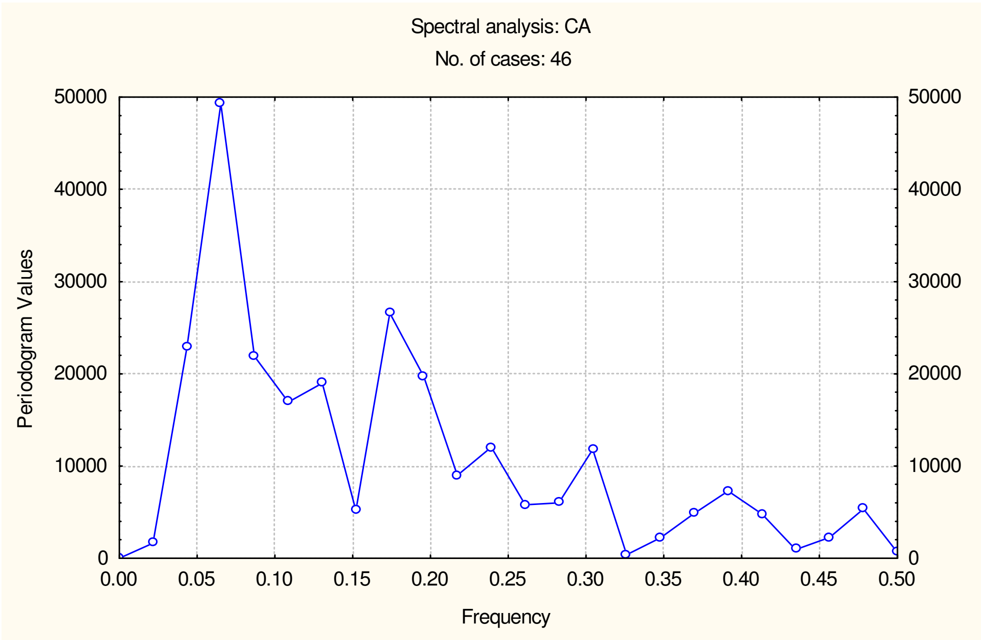


(c)

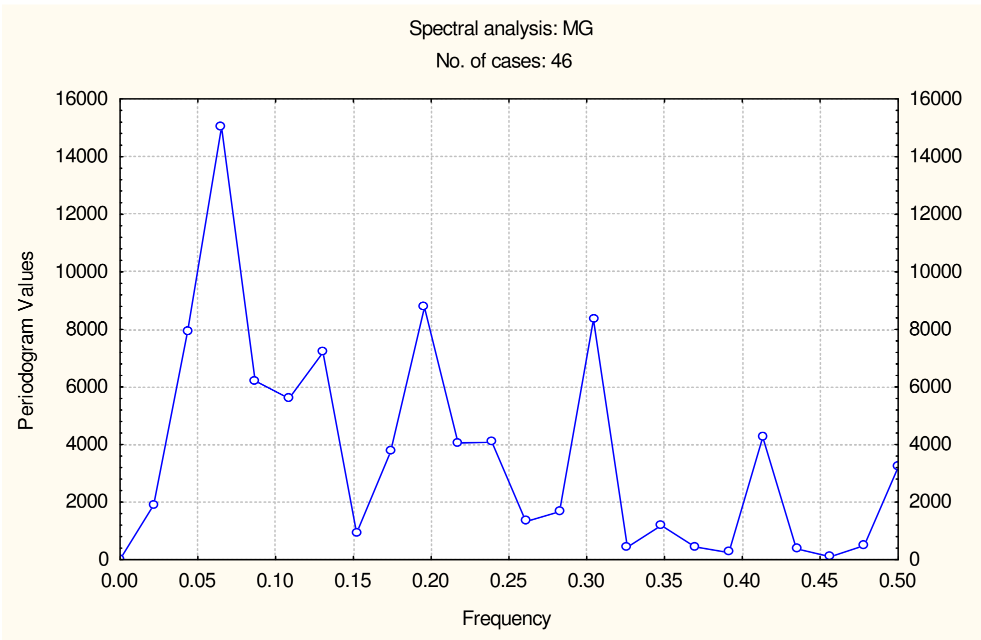


(d)

Fig. 8: Periodogram of EC (a), T.H. (b), TSS (c) and Q (d) for Diyala river



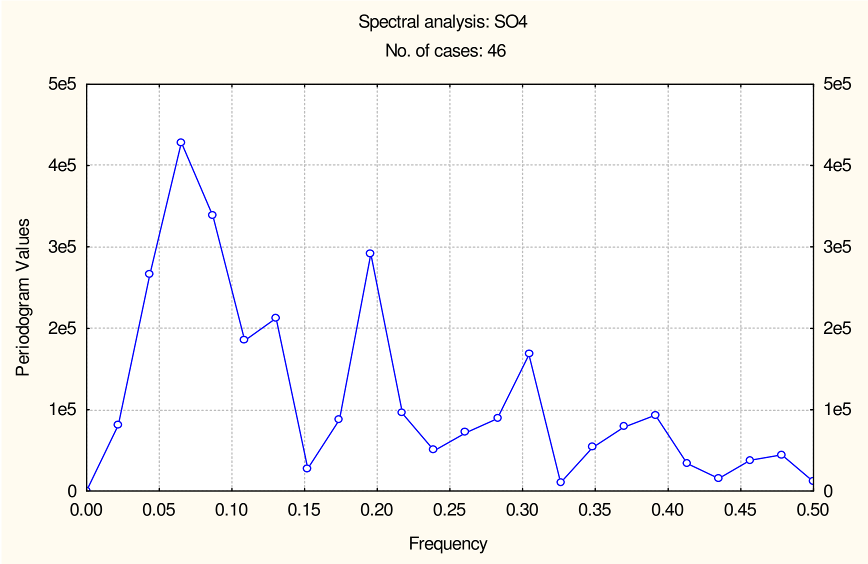
(a)



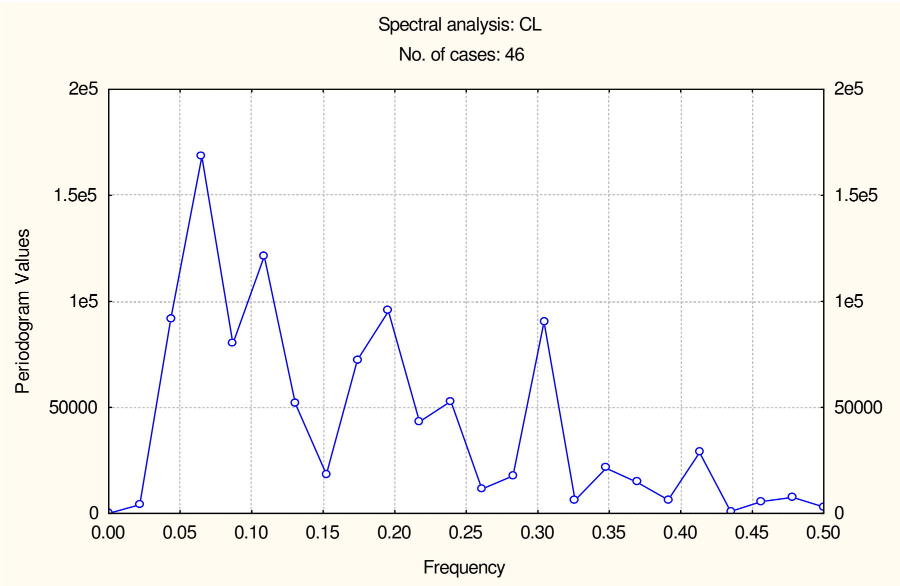
(b)

Fig. 9: Periodogram of Ca (a) and Mg (b) for Diyala River

(a)



(b)



(c)

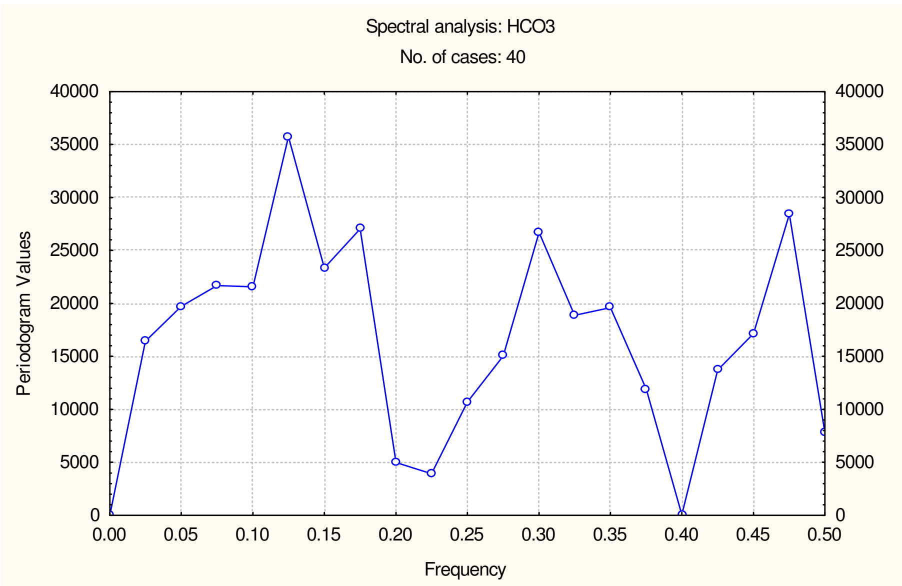


Fig. 10: Periodogram of SO_4 (a), cl (b), and HCO_3 (c)