FP7 2013 Cooperation Work Programme
Theme 6: Environment (Including Climate Change)

Novel indicators for identifying critical *INFRA*structure at *RISK* from Natural Hazards

Deliverable 5.4

Wavelet models of Environmental Cycles

Primary Author	Yuliya Avdeeva and Pieter van Gelder / Probabilistic Solutions Consult and Training BV (PSCT)
WP	5
Submission Date	20/11/ 2015
Primary Reviewer	Khaled Taalab and Tao Cheng / University College London (UCL)
Dissemination Level	PU

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 603960.

Project Information

Project Duration:	1/10/2013 - 30/09/2016
Project Coordinator:	Professor Eugene O' Brien Roughan & O' Donovan Limited eugene.obrien@rod.ie
Work Programme:	2013 Cooperation Theme 6: Environment (Including Climate Change).
Call Topic:	Env.2013.6.4-4 Towards Stress Testing of Critical Infrastructure Against Natural Hazards-FP7-ENV-2013-two stage.
Project Website:	www.infrarisk-fp7.eu

Partners:

Roughan & O' Donovan Limited, Ireland

Eidgenössische Technische Hochschule Zürich, Switzerland.

Dragados SA, Spain.

Gavin and Doherty Geosolutions Ltd., Ireland.

Probabilistic Solutions Consult and Training BV, Netherlands.

Agencia Estatal Consejo Superior de Investigaciones Científicas, Spain.

University College London, United Kingdom.

PSJ, Netherlands.

Stiftelsen SINTEF, Norway.

Ritchey Consulting AB, Sweden.

University of Southampton (IT Innovation Centre), United Kingdom.

Document Information

Version	Date	Description	Primary Author
Rev01	7/10/2015	Draft for comment	Avdeeva & Van Gelder
	16/10/2015	Review	Khaled Taalab and Cheng Tao (UCL)
Rev02	31/10/2015	Draft version	Avdeeva & Van Gelder
	05/11/2015	Review	Robert Corbally/Mark Tucker (ROD)
Rev03	20/11/2015	Final version for submission	Avdeeva & Van Gelder

Executive Summary

This report describes the Deliverable D5.4 – a description of wavelet analysis of environmental cycles. This type of analysis can be used to evaluate the spatial and temporal fluctuations of environmental variables affecting infrastructure which are exposed to natural hazards.

The INFRARISK project is concerned with the behaviour of critical infrastructure, such as road and rail networks, when subjected to natural hazards such as landslides, floods, earthquakes or a combination of all three. These natural hazards, as well as the behaviour of the infrastructure when the natural hazards occur, vary both spatially and temporally. It is shown in this deliverable that wavelets can be considered as a very suitable and powerful approach to model the temporal and spatial variability at different scales.

Non-stationary time series in geophysics, atmospheric science and environmental engineering, which show temporal and spatial variability at different scales, can be analysed in 'wavelet space' in order to identify the main characteristics in time and space. Wavelet analyses are used to understand the space-time cycles of the "loads" on critical infrastructures (precipitation, runoff, earthquake magnitudes, etc).

In order to perform a wavelet analysis, data needs to be provided as time series (not necessarily with fixed time intervals) at multiple (not necessarily equidistant) locations. It is shown in this deliverable that typical preparatory work involving zoning of spatial areas, autocorrelation analyses, integral curve analyses, and Fourier analyses, are necessary before the actual wavelet analysis can be performed. The analysis establishes zones of synchronization or non-synchronization of fluctuations across time and across territory - quantifying possible changes in the fluctuations of for instance water content of rivers – determining any possible phase shift in the cycles, etc.

Quantification of the relationship between natural hazards, the environment and critical infrastructure benefits from using spatio-temporal models. Wavelet models help us to understand the space-time cycles of the "loads" on the critical infrastructures (precipitation, runoff, etc). It may point out areas where critical infrastructures are exposed to higher stress levels or periods in the near future with higher stress levels, which can be exploited when designing stress tests for Critical Infrastructure (CIs).

Table of Contents

1.0 INTRODUCTION

The INFRARISK project is concerned with the behaviour of critical infrastructure, with a focus on transport infrastructure such as road and rail networks, when subjected to natural hazards such as landslides, floods, earthquakes or a combination of all three. These natural hazards, as well as the behaviour of the infrastructure when the natural hazards occur, vary both spatially and temporally. In this deliverable it will be shown that wavelets can be considered as a very suitable and powerful approach to model the temporal and spatial variability at different scales. A ready toolkit is available to conduct these wavelet analyses, via a web-based calculation tool by Torrence and Compo (1998).

In recent years a large amount of research has been published investigating the impact of changes in the global and regional climate and the impact of economic activity on the run-off of rivers. The number of works (Druginin et. al, 1991; Babkin, 1979; Zemtsov, 2000; Levin et.al, 2001; Shorthouse and Arnell, 1997; Cluis, 1998; Labat, 2006) are devoted to the comparative study of the long-range variability of run-off and variations in solar recovery, atmospheric circulation and hydrometeorological indices. Both statistical methods (Zemtsov et.al.,2000; van Gelder et.al., 2000; Lubushin et. al., 2006; Pekarov et.al., 2003; Goroshko and Burakov, 2007) and deterministic methods (Vinogradov,1988; Kuchment et.al. 1990) have been applied in these analyses.

Although the majority of this research has been devoted to the study of specific regions, Kalinin sought to generalize the materials of observation on a global plain and this was followed up by Kritsky and Menkel ((Kalinin, 1968; Kritsky and Menkel, 1981). The long range streamflow and runoff fluctuation of the major rivers of the world are also in focus of the work of Probst and Tardy and Labat (Probst, Tardy, 1987; Labat, 2006).

The aim of this report is to conduct a time-spatial generalization, using wavelet theory, of the observation material, specifically collected for this purpose, for the river basins of Eurasia with the aim of establishing zones of synchronization or non-synchronization of fluctuations of annual river run-off across time and across territory - quantifying possible changes in the fluctuations of water content of rivers in recent years – determining any possible phase shift in the river cycles of the rivers of Europe and Asia.

This report is organised as follows. First, the collected datasets for this study are described. Then, an attempt of zoning of the river basins according to their conditions of the runoff formation is made. Subsequently, correlation analyses of run-off fluctuation are carried out in an attempt to identify regions with synchronous variation of runoff. An analysis of cycles of variation of runoff is carried out using wavelets. A pre-existing toolkit is used for this. The report ends with a summary of the main conclusions.

2.0 ENVIRONMENTAL CYCLES

Before starting the use of wavelet theory on environmental cycles, in this section an overview of a large scale, spatial and temporal, database is given, followed by all pre-processing data analytics which are necessary prior to a wavelet analysis.

2.1 A large spatial and temporal environmetric database

The territory of study covers different natural regions of the continent of Eurasia: from subequatorial in Iran, India and China to the subarctic and Arctic in Europe (Scandinavia) and Asia (Siberia). In total, seventy-nine series of observations of annual river discharge were selected (Figure 2.1). The list of rivers with the indication of river gauge, geographical coordinates, number of years of observations, period of observations is given in Table A.1, Appendix A.

The following criteria were adopted in the selection of river basins:

1) The rivers selected must, as far as possible, serve to give a complete picture of the vast territory of Eurasia. For this purpose, they should flow within the limits of one natural region and reflect the run-off of this zone.
2) The duration of observations of river discharge must be a minimum of 20 years, which makes it possible to include territories which have been less extensively studied.
3) The river basins selected must be either virtually untouched by economic activity or be characterized by stable conditions of economic activity.

Using these criteria to carry out a selection of river basins, 79 rivers were chosen, having, on average, an area of drainage basin from 1000 to 100000 km². Due to the unevenness of availability of information in different countries, it was necessary to vary the period of observations from 22 years for the rivers of India and Iran to 175-190 years on the rivers of Germany and Latvia. The Global Runoff Data Centre (GRDC- http://www.bafg.de/GRDC/EN/Home/homepage_node.html) provided data on annual river discharge.

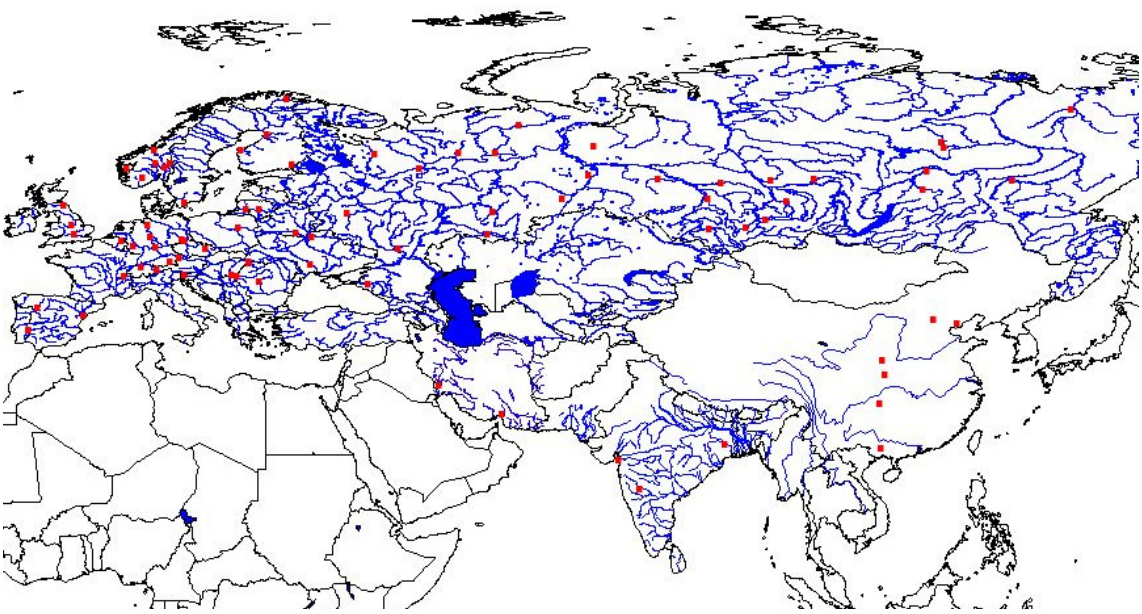


Figure 2.1: The location of the 79 stations with the observation of the annual runoff

Unfortunately, some countries have stopped sending information to the GRDC in recent years. As a result, the latest observation readings for Spanish rivers relate to 1992, Norwegian rivers to the period 1997-2002 and for the rivers in the European part of Russia to the period 1985-1998.

In order to obtain the missing sets of data additional sources of information were used such as the site of the Mediterranean Hydrological Cycle Observing System (Med-HYCOS project - http://medhycos.mpl.ird.fr), the site of World Data Base of River Discharge (RIVDIS - http://www.rivdis.sr.unh.edu/), and the site of the UNESCO International Hydrological Program (http://webworld.unesco.org/water/ihp/db/shiklomanov/).

Data on the high-altitude position of the river basins is taken from a physico-geographical map (the World Atlas, 2001). Characteristics of river basins such as the percentage of forestation, the percentage of the agricultural use of the land, the density of population, etc., were obtained from the Atlas of Available Water Resources (eAtlas) which can be found at http://www.waterandnature.org/eatlas/html

For the Russian river basins, data is obtained from the Water Resources Book (Water Resources Book).

For Chinese rivers the data used came from the site of The Ministry of Water Resources of China (http://www.mwr.gov.ch/english/index.asp) For Indian river basins – from the site of The Ministry of the Water Commission of India (http://cwc.nic.in).

Data about climatic characteristics such as average annual total precipitation and average annual air temperature was obtained with the help of a climatic chart, published on the site of the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) - http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#

Data missing from the sets of observations of river discharge were restored, when possible, in accordance with statistical connections with the rivers - analogues, with the correlation coefficient of the river being investigated and river- analogue R>0.7.

Water discharge on the majority of rivers is subject to the effects of economic activity to a greater or lesser degree. This applies particularly to European rivers. However, having checked the uniformity of the sets using the "Student Criteria of Average Values" and the Fisher criterion for evaluating the uniformity of dispersion (The time-spatial fluctuations of the drainage of the rivers of the USSR, 1988.) it was seen that, for the majority of rivers, the average values of annual water discharge were uniform. However, a significant inconsistency (r=1% and 5%) was revealed for 9 rivers (Table A.2, Appendix A). Unfortunately, the observation material available does not make it possible to speak with confidence about with what precisely these inconsistencies are connected - with climate changes or with anthropogenic action.

2.2 Zoning of River Basins

This report has adopted factor and remote analysis as the basis for the study of the development of the rivers, and similarly for the long-range variability of annual run-off. This permits the implementation of an integral approach to the study (Antipov and Koritny, 1981; Nikitin and Zemtsov, 1986; Zemtsov, 2004). Factor analysis allows to dimensionalize the data and to create the generalized indices, which have the greatest effect on run-off. The factor model applied takes the following form:

$$Z_j = \Sigma a_{jr} f_r + \varepsilon_j \,, \qquad (2.1)$$

where Z_j – *j*- variable, f_{ri} – *r*-common factor, a_{jr} – factor load of *j*-variable on *r*-common factor, ε_j – casual constituent of variable Z_j.

In order to eliminate the effect of dimensionality and to ensure the comparability of variables, the initial data is normalized, for example, according to standard deviation:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_j}{\sigma_j} \qquad (2.2)$$

where $\overline{X}_j$ - mean value of variable X_{ij} for row of object, σ_j - standard quadratic deviation.

The two variants of the normalization of initial data were calculated. In the first version all numbers of initial data were normalized according to standard deviation. In the second case the initial data was converted in the following manner:

Area of river basin and density of population:

$$Z_{ij} = \ln(X_{ij}) \Big/ \sigma_j(\ln(X_{ij})) \qquad (2.3)$$

Altitude characteristic of river basin:

$$Z_{ij} = \sqrt{X_{ij}} \Big/ \sigma_j(\sqrt{X_{ij}}) \qquad (2.4)$$

Longitude and latitude, characteristics of river basin as area of forestation, swamp and land uses, climatic characteristics (annual precipitation and the average annual air temperature) etc.:

$$Z_{ij} = X_{ij} \Big/ \sigma_j(X_{ij}) \qquad (2.5)$$

The number of factors is assigned in such a way that they should describe a major portion of the dispersion of initial data, and the residual variance, connected with random components ε_j , was sufficiently small (based on using the rule of thumb of keeping enough factors to account for 80% of the variation). The factors (in the terminology of factor analysis - general factors) obtained as a result of calculation are mutually orthogonal. The correction of the position of factor axes is achieved by their rotation, in particular, by the method of varimaks, which consists in the maximization of the dispersion of loads on the factors (Iberla, 1980).

In this work the following geographical and topographico-hydrological characteristics were examined: the coordinate of gauges (φ_1 – latitude; φ_2 – latitude (^{0})); the area of river basin (F, km^2); the high-altitude position of the river basin, defined as the average of the maximum and minimum heights of basin (H, m); average annual total precipitation (X, mm); the average annual air temperature (T, ^{0}C); the forest area of river basin (f_l, %); area of lakes and swamps in the river basin (f_l, %); the area of the land in agricultural use (f_a, %); the area of the urbanized territory (f_u, %); the density of population (P, people/km^2).

Thus, 11 characteristics were used. Four variants of the initial data were analyzed as outlined below:

All 11 characteristics are normalised according to the mean-square deviation;
Characteristics are normalised also, as in the previous version, but the area of river basin is excluded from the analysis;
All 11 characteristics are normalised according to the equations (3-5);
Characteristics are normalised also as in previous variant; the area of drainage basin is excluded.
Analysis showed that with the diverse variants of initial data, three groups of factors are distinguished, which describe 73-80 % of the dispersions of initial information.

The first generalized factor is the characteristic of the river basin and includes the area of the basin occupied with forest, the area of basin, occupied with agricultural land, the average density of population and the average annual temperature of air. This factor is described from 39 to 46 % dispersion of initial data. The second factor includes the index of the height of the basin. This factor is described from 13 to 16% of dispersion of initial data. The third group is the characteristic of the position of gauge (longitude) and average total precipitation, which characterizes the moistening of the basin. With the use of 1 variant of data set, the third factor includes, instead of the average total precipitation, the area of the basin, along with the use of 3 variants: gauge's longitude, average total precipitation and the area of river basin. This section describes the convergence of these factors. The multiplication of the generalized factors to their loads were applied to characterise the river.

Furthermore, it is possible to divide the territory into regions with a similar pattern of the long-standing fluctuations of run-off, by assuming that the influence of each factor, as far as possible, is manifested within the specific geographic boundaries. This differentiation is carried out by the method of remote analysis.

The basic idea of this method is based on the fact that each object (river basin) being investigated, characterized by signs or factors (m), is represented by a point in space with the dimensionality (n), which is determined by the number of variables. The initial data can be represented in the form of the matrix:

$$\langle P \rangle = \begin{vmatrix} P_{1,1} P_{1,2} \dots P_{1,m} \\ P_{2,1} P_{2,2} \dots P_{2,m} \\ \dots\dots\dots\dots\dots\dots \\ P_{n,1} P_{n,2} \dots P_{nm} \end{vmatrix} \qquad (2.6)$$

The classification of objects to the groups is determined on the basis of the index of proximity d (x.y), which is the distance between two points (objects) and is the characteristic of similarity between them. The Euclidean measure is the most commonly used measure:

$$d_{ij} = \sqrt{\sum_{n=1}^{m} (P_{in} - P_{jn})^2} \qquad (2.7)$$

The method adopted by this report is cluster analysis by the method of k-means, which gives good results with a large number of observations (Aivazian and Mhitarian, 2001). In addition, several different sets of initial data were used in the cluster analysis. The first set includes the normalized values of the variables which have a close connection with run-off: the longitude of gauge; the area of river basin; the area of the basin, occupied by agricultural land; the characteristic of the high-altitude position of the basin; average total precipitation. The other sets based on factor analysis i.e. the generalized factors multiplied by loads were used as the characteristics of the river.

In order to determine the optimum quantity of clusters, trial calculations with different quantities of the clusters were carried out, ranging from 5 to 15, and preliminary hierarchical grouping was also assessed using the visual analysis of Dendogramme. Preliminary partition by hierarchical clustering showed the presence of 7 groups. However, visual analysis was hindered because of the inherent structure of the data. Trial calculations for different numbers of clusters carried out with the use of the Silhouette method (Rousseeuw ,1987) showed that the best results gave a division into 7 and 5 clusters. Finally, the solution agreed upon was a division into 7 clusters.

Although the sets of initial data are different, the regions coincide for all practical purposes, Figure 2.2. The first region includes the rivers of Southern Europe: the Gaudiana, Ebro, Esla, Guadalquiviri, Mures, Olt, Somes, Maritsa, and the Tivere. The rivers of Great Britain, Northern Europe and some of the rivers of Central Europe form the second group. The rivers involved are: the Trent, Tweed, Thames, Maas, Weser, Main, Elbe, Danube, Moselle, Morava, and the Bug. The third group comprises the remaining rivers of Central Europe and of South-Western Scandinavia. The fourth group of rivers includes the rivers of southern and Eastern Scandinavia, the northern area of Eastern European and the West Siberian plains: the rivers Glomma, Clara, Helgea, Vuoksi, Iijoki, Kyronjoki, Usa, Pechora, Vym, Iset, Konda, Ket, and Vasugan The fifth group of rivers consists of the rivers of the Eastern European plain and of the South Urals: rivers Nemunas, Pripiat, Southern Bug, Desna, Belaya, Oka, Ural, Sukhona, Onega, and Medveditsa. Next, the sixth group is made up of the rivers of Central and East Siberia and of the Far East: rivers Bia, Tom, Chadobets, Bolshoy Pit, Kan, Tuba, Abakan, Vitim, Nyuya, Aldan, Markha, Bytantay, Selemdga, Nimam, Nimelen, and Hilok. The last (the seventh) group of rivers includes the rivers of South West and East Asia: rivers Kuban, Minab, Karun, Naryn, Narmada, Damodar, Yu Jiang, Wu Jiang, Luan He, Youngding, Jing He and Han Shui.

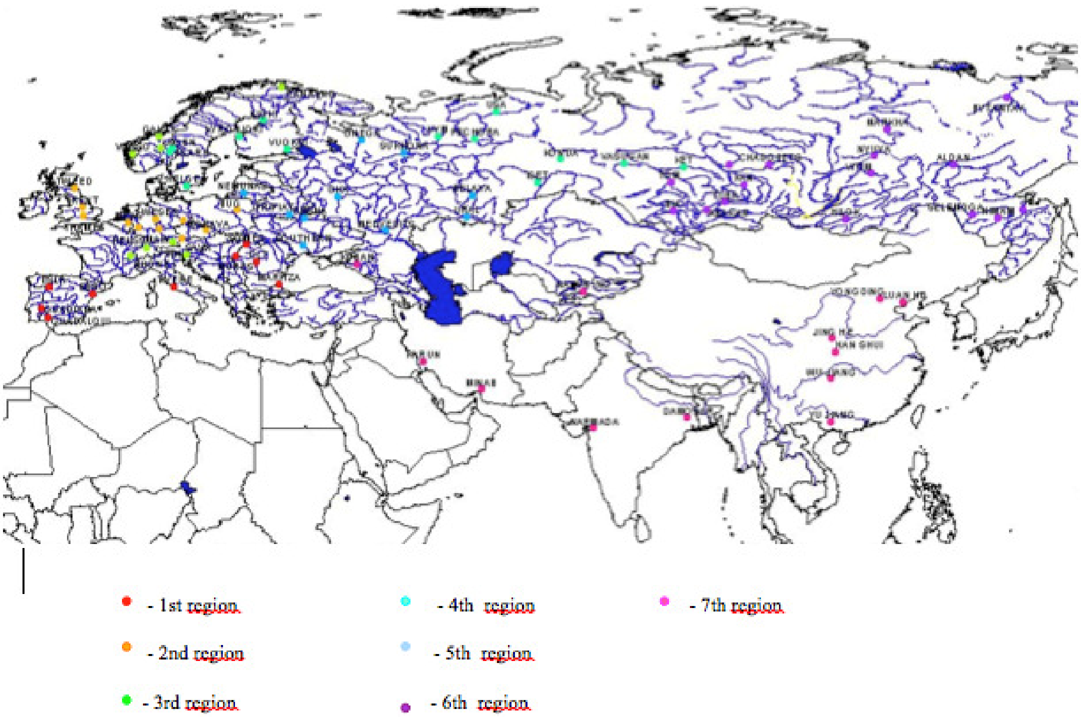


Figure 2.2: Zoning of river basins

The differences in the natural climatic conditions (Table A.3, Appendix A), which were reflected in the formation of clusters lead to the differences in the quantitative indices of the available water resources and long-standing fluctuations of run-off. Consequently, the third region, which is characterized by a high annual precipitation (in the range of 1200-2500 mm), and also by a heavy score in the high-altitude index of basins, brings together in its group the most water-abundant rivers: the modulus of annual run-off comprises here on average from 30 to 50 l/s per km^2 and the coefficient of run-off is 0.6-0.8. Variability of run-off over the years is low (a coefficient of variation - 0.15-0.2). The rivers of the first and second groups, which are based on territory that is relatively well moistened and well developed for agricultural use, have a module of run-off 6-10 l/s per km^2 and 8 -15 l/s per km^2, respectively. The coefficient of run-off here is relatively low, recorded at 0.2-0.4. The rivers of the first region, which are characterized by a higher high-altitude position of basins, are characterized by high coefficients of variation in the annual run-off in comparison with the rivers of the second region which flow over a territory of plains, (0.3-0.8 and 0.2-0.3, respectively). The fourth and seventh groups, which include rivers more disparate in their geographical location, are characterized by a large spread in the quantitative characteristics of water content within the group. The modules of drainage in the fourth group range from 2-5 to 10-17 l/s per km^2 and the coefficients of run-off from 0.3 to 0.7. The coefficient of variation in run-off is on average 0.2-0.3. An exception is the river Iset, where the coefficient of variation is equal to 0.55. The fifth group encompasses the East European rivers, which flow predominantly over a territory of plains. Here the modules of drainage range from 5 to 9 l/s per km^2, the coefficient of run-off is 0.3-0.5 and the coefficient of variation is 0.3-0.6. The sixth group of rivers (Siberian and Far Eastern rivers) is characterised by a contrast between the rivers with a lower altitude position of basins, which have low modules of run-off (3-8 l/s km^2) and the rivers which flow through the mountain regions with much heavier runoff (20 l/s per km^2). The coefficients of run-off of these rivers are relatively high - 0.4-0.8 and the coefficients of variation are 0.2-0.3. Into the seventh grouping of rivers enter the rivers of South West and East Asia. Two subgroups are noted for the rivers within this group: the first with a module of run-off from 1 to 3 l/s per km^2, with low coefficients of run-off (about 0.3) and high coefficients of variation of run-off (0.4-0.8). For the rivers of the second subgroup the module of run-off varies on average from 10 to 20 l/s per km^2, while coefficients of run-off are from 0.4 to 0.7, and coefficients of variation from 0.2-0.4.

We have seen therefore that by means of cluster analysis, separate regions were delineated which differed in respect of specific generalities in the characteristics of annual discharge and its long-range variability. However striking changes are not observed when moving from one region to another. There are no sharply defined boundaries between the clusters and on the contrary there are areas where regions merge. Moreover, within the clusters themselves, differences are evident in the indices of run-off and its long-range variability. It would be helpful to make a further breakdown of classification for the rivers of Europe and Asia, which would consider the special features of intra-annual run-off distribution, the types of the predominant sources of rivers, etc. Similar classifications for separate basins are given in the works of many authors (Evstigneev et al.,1975; Kuzin and Babkin, 1979; Zemtsov,2004; van Gelder and et. al., 1999). Unfortunately, uneven availability of information of the river basins of Europe and Asia did not allow us to conduct this more detailed classification. An increase in the number of clusters while using the same volume of initial information has the effect of breaking up the European territory into a larger number of smaller clusters, while for the Asian section the number of clusters remains the same and each remains intact. Obviously this is connected with the insufficient quantity of information available for the Asian part of the continent. In the interest of overall balance, therefore, it was decided that for the purposes of the comparative analysis of the long-standing fluctuations of the rivers of Europe and Asia it was appropriate to stay with the division into the larger clusters.

3.0 CORRELATIONS IN RUNOFF FLUCTATION

The work of many authors, who have researched the long-term fluctuations of annual river run-off (Ratkovich, 1976; Spatial and temporal variations in the river runoff of the USSR, 1988; Zemtsov, 2004) have revealed a reliable correlation between the annual run-off observed in adjacent years. Their calculations showed that on many rivers of Eurasia there is a close autocorrelation connection, which diminishes at a significant rate with an increase in the time interval. Autocorrelation coefficients for the period from the 1st of year of proximity are in the range of 0.3-0.5, while at the 6th-8th years, coefficients obtained are already totally insignificant, varying in the range of -0.2-0.2. In the European region a high correlation coefficient between the drainage of adjacent years (about 0.5) is observed on the rivers of the south of Spain: the rivers Guadalquivir and Ebro and on the river of Italy - the Tevere. On the majority of West European rivers the autocorrelation coefficient varies from 0.15 to 0.4 decreasing from the south to the north to 0.1-0.15 (the rivers of Norway). In the northwest of the European region, the rivers of Russia produce autocorrelation coefficients equal to 0.2-0.3. For the rivers of the Asian part of the continent the highest autocorrelation coefficients are identified for the rivers of the southern taiga of West Siberia (about 0.5). However, for the majority of Asian rivers the coefficient varies within a range of 0.15-0.35.

In the work of Hydrometeoizdat (1988), a study is made of the rivers of the former U.S.S.R., in order to examine the dependence of the correlation coefficient between the drainage of adjacent years upon physicogeographical factors, such as variation in water content and the changeability of annual run-off. Our present study has taken note of the close connection of autocorrelation coefficients with the coefficient of variation of the annual river run-off on the Asian part of the continent (R=0.57). It is observed that, with an increase in the coefficient of variation, the value of the correlation coefficient between the run-off of adjacent years grows accordingly. For the rivers of Europe such a close dependence could not be obtained (R=0.33). However, it can be gathered that the increase in the water content and the decrease in the changeability of runoff also decrease the autocorrelation coefficient.

Corrections were introduced into the calculation of the coefficient of variation. These proved to be significant only for two rivers: the Guadalquivir and the Minub (Table 3.1).

River-gauge	calculated Cv	Cv with correction
Guadalquivir – Alcala Del Rio	0.84	0.86
Minub – Brantin	0.83	0.87

Table 3.1: Variation coefficient of annual runoff

The annual run-off of rivers is also correlated spatially. Kalinin (Kalinin, 1968) constructed isocorrelation maps of the annual run-off of rivers in the northern hemisphere. The analysis produced from these showed that the zones of synchronous vibration of run-off in this region are quite extensive. It is Kalinin's approach that we have used in our own research into the spatial fluctuations of the annual river run-off of Eurasia, and, as before, we update this account with observations made in the recent decades. The following rivers, situated in the chosen regions, were selected as reference rivers: the Ebro, Maas, Ina, N'yumanas, Vasyugan, Tuba and Karun. Correlation coefficients were calculated within four periods of the observations: 1965-1985, 1950-1990, 1940-2000. The period 1965-1985 is the period which is covered by observation on the majority of rivers.

However, authenticity in the determination of correlation coefficient proved very tenuous while dealing with a 20 year observation time span and with low values of correlation coefficients. Niven and Deutsch (2012) showed that the true value of the correlation coefficient obtained during a 20 year period of observations, -0.4, can vary within a range from -0.7 to 0.05. Our calculations showed the most unstable to be the coefficients of paired correlation of the river Karun with the rivers of Western Europe (Table B.1, Appendix B). This is possibly explained by heterogeneity in the series of observations for the annual river run-off of the river Karun (see Table 2). From a statistical point of view, the most reliable correlation coefficients available are higher than 0.6 or - 0.6. Even such values appear low. However, in the work of Kalinin, it is emphasized that, during the overall generalization of a large amount of data on a territory, the authenticity of this data is increased.

The isocorrelation maps (Figure 3.1 and Figure 3.2) were constructed according to the correlation coefficients that had been calculated. From the maps it is possible to form a judgement about the presence of positive and negative correlation fields on the run-off of Eurasian rivers, which are outlined with sufficient clarity. It is evident that the isocorrelations are elongated more in the latitudinal, than in the meridional direction. This is caused to some extent by the latitudinal zonality of natural conditions and, generally, it will be linked with the nature of the circulation of atmosphere, with western air-mass transfer predominating above a larger area of territory. [Alisov, Kalinin,Byrakov, Zemtsov, 2004].

If as a reference river we take a river of South Europe, the river Ebro, then we can see from the map a region of positive correlation, located in South Europe (Figure 3.1(a)). Another region of positive correlation penetrates the European territory of Russia, covering West and Central Siberia. This region is strongly elongated eastwards, being located under the effect of the Western transfer. Positive correlation coefficients are observed also on Russia's eastern coast and in North China, although here it does not have this strong defined form. Regions of inverse correlation are located in East and South-western Asia (the territory of East Siberia and Central and South China). Correlation coefficients are here in the range of -0.4 - -0.6. Lines of isocorrelations are elongated in a south-easterly direction.

The shapes of isocorrelations, constructed for the reference river Maas, have a more concentric form (Figure 3.1 (b)). A zone of relatively high positive correlation (R=0.6-0.8) is located over Europe. These correlation coefficients diminish at the northern extremity of the Scandinavian Peninsula, taking on slightly negative values. Regions with an inverse correlation are located also on the southern extremity of the European part of the continent, the northern part of the Asian continent, and in eastern and south-eastern Asia. These regions are more elongated in the latitudinal direction, than regions with a positive correlation. Isocorrelations with R>0 are located in Central and South Siberia. In comparison with the region of positive correlation, noted with the reference river Ebro, the centre of this field is a little displaced in a south-eastern direction.

The Inn river basin is the river basin of central Europe. A region of higher correlation (R=0.4-0.9) covers Central Europe and the southern part of the European territory of Russia (Figure 3.1(c)). Another region with a positive correlation (R to 0.5) occupies the south of Eastern Siberia, and the central and northern part of China. Regions of weak inverse correlation are traced in the centre of the European part of Russia, West and Central Siberia, South and south of Eastern Asia, and also along the western and eastern fringes of the continent.

If we take the river Neman as the reference river, then it is evident that a region of high positive correlation (R >0.6) covers a large part of Europe, decreasing to the west, to the north and to the south, where the correlation coefficients acquire negative values (Figure 3.1(d)). Isocorrelations with negative values are located in a large area of the Asian part of the continent. This region consists of West Siberia, South-Eastern Asia and the Far East. A region with the positive values of R is located to the north of the Asian section of the continent.

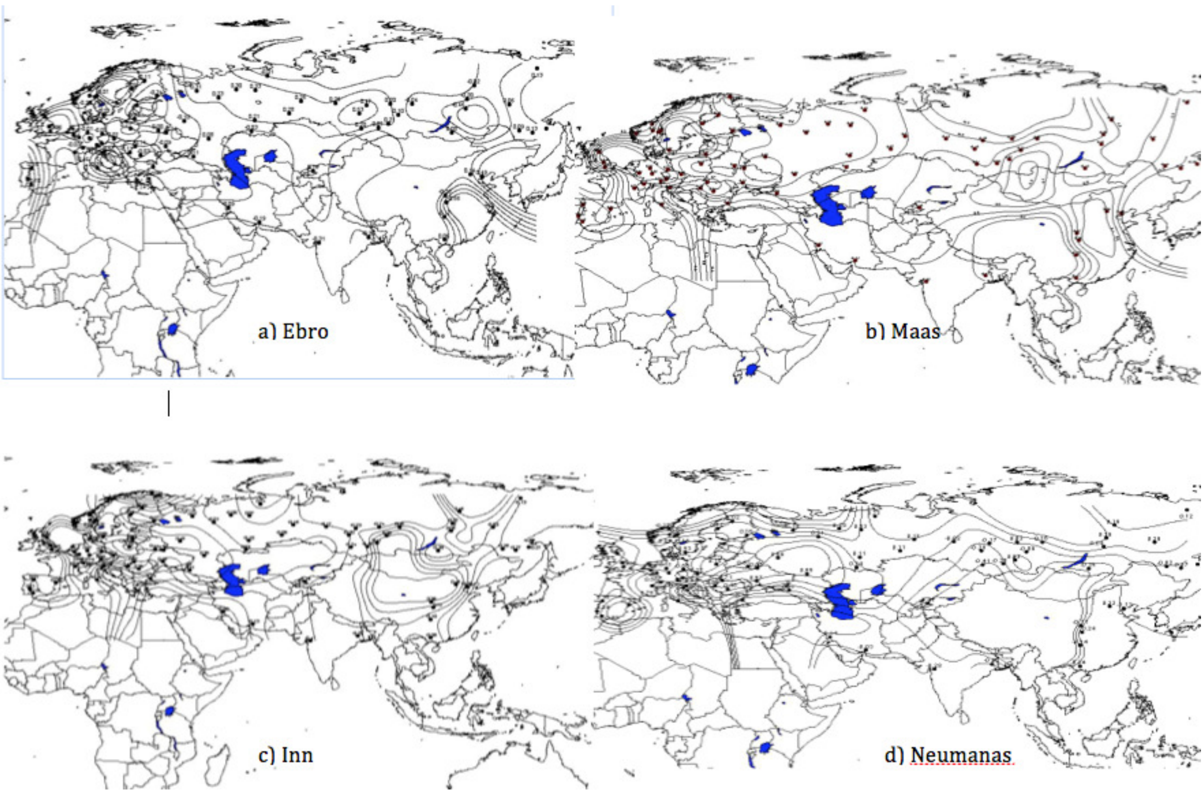


Figure 3.1: Isocorrelation lines of annual river runoff

The Vasyugan river basin is located in the forest zone of the Western Siberian plain. A region of positive correlation is located over the territory of the Urals, and West and Central Siberia (R=0.4-0.6) (Figure 3.2(a)). Lines of isocorrelation are strongly elongated in a north-eastern direction. Another region with R>0 occupies the western end of continental Eurasia. A region with inverse correlation, which has several local centres (R=0.4), is located over the territory of Central Europe. These isocorrelations do not have a clearly defined orientation. Inverse correlation is noted also between the run-off of the Vasyugan river and the rivers of south-western, south-eastern Asia and the northern parts of the Far East.

The isocorrelations, which were constructed for the reference river basin of the Tuba (Figure 3.2(b)), have an even more defined latitudinal orientation than the isocorrelations, which were constructed for the Vasugan river basin. Some regions with positive correlation are located in Central Europe, but the values of the correlation coefficients are low (not exceeding 0.4). On moving northwards (to the Scandinavian peninsula) and southwards R rapidly changes sign from positive to negative. Two separate centres of negative isocorrelations, which have shape similar to a circle, are noted, one to the northwest of Scandinavia and the second in the southern part of Finland.

A region of high positive correlation is located in the Asian part of the continent: in Siberia and North China. A region of inverse correlation is positioned over the south of East Siberia, but R values here are low.

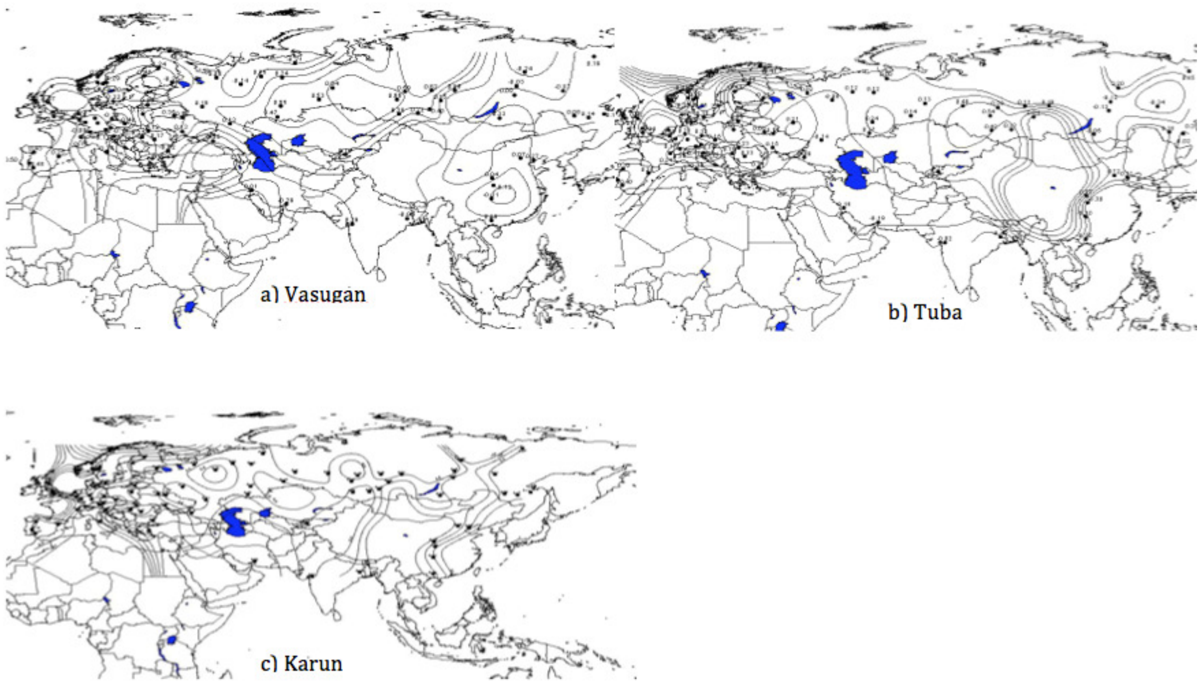


Figure 3.2: Isocorrelation lines of annual river runoff

A region of high positive correlation is located in the Asian part of the continent: in Siberia and North China. A region of inverse correlation is positioned over the south of East Siberia, but R values here are low.

If we select the basin of the Karun river from the river basins of south-western and east Asia to serve as the reference basin, then it is evident (Figure 3.2(c)) that a clear picture of distribution of isocorrelations over the territory is not obtained. The correlation coefficients of the average annual run-off of the Karun river with the average annual run-off of the majority of the rivers of Europe and Asia are negative, but these are insignificant (up to -0.4). These results are possibly connected with heterogeneous in the series of observations of the annual water discharge for the Karun river. Unfortunately we do possess observations of sufficient duration for the group of rivers of southwest and east Asia. An attempt to obtain a clearer idea of the correlation between the annual run-off of these rivers and the rest of the rivers of Eurasia according to other reference basins (for example the river Khan Shui) did not prove successful.

An analysis of the spatial correlation function (SCF) of annual water discharge, using the Fisher transformation showed that the function cannot be considered uniform for the whole territory of Eurasia (Figure 3.3, Table 3.2). We therefore calculated SCF for the separate groups of rivers. The resultant estimation of statistical uniformity SCF for the separate regions showed that the third region (the rivers of central Europe and southwest Scandinavia) and the fourth region (the rivers of the south and the east of Scandinavia, of north-eastern Europe and the rivers of western Siberian plain) can be regarded as uniform throughout the full extent of their territory. The SCF of the rivers of the second group (the rivers of Great Britain, northern Europe and some of the rivers of central Europe) can be regarded as uniform, if we exclude the river Bug from this regional group of rivers. The SCF of the remaining regions proved heterogeneous. These regions were: the first region - the rivers of southern Europe, the fifth- the rivers of the eastern European plain and the South Urals, the sixth- the rivers of central and eastern Siberia and the Far East, and the seventh region - the rivers of south-western and East Asia. Their only use would be in the making of qualitative assessments. SCF of the third and fourth regions can be used for quantitative assessments while solving the problems of monitoring available water resources, for example, during the changeover from a short series of annual water discharge to a long-lasting series.

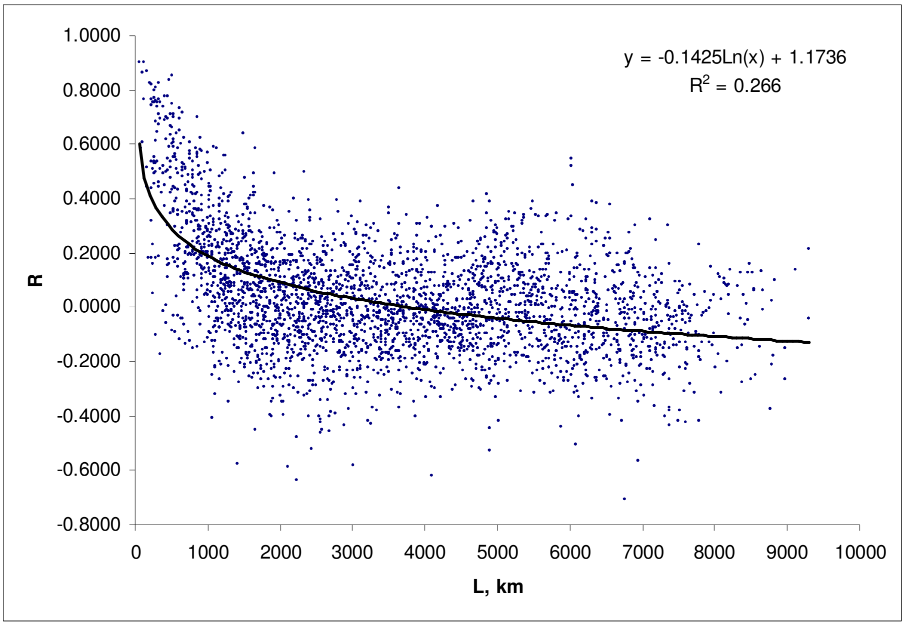


Figure 3.3: Spatial correlation function of the annual river runoff

Region	Number of observations	Critical value	Empirical value	Result
All territory	3081	1.06	3.76	Hetero
1	36	1.76	2.32	Hetero
2	66	1.51	1.76	Hetero
3	21	2.12	1.89	Homo
4	78	1.46	1.36	Homo
5	45	1.65	1.79	Hetero
6	120	1.35	2.84	Hetero
7	66	1.51	14.01	Hetero

Table 3.2: Homogeneity test of spatial correlation function of the annual river runoff using the Fisher test (significant level 5%)

4.0 CYCLES IN FLUCTUATION OF RUNOFF

4.1 The integral curve of the runoff

The residual integral curve method for the determination of the cyclical variations of hydrometeorological characteristics was first proposed by Glushkov. It was Andreianov (Afanasev, 1967), who introduced the comparative analysis of different material on the basis of the normalization of the residual integral curve of the specific runoff coefficients.

The method used in the calculation of the residual integral curve is as follows: firstly, the specific runoff coefficients for this series of observations are calculated (K_i):

$$K_i=Q_i/Q_{average}, \qquad (4.1)$$

where Q_i denotes the value of the runoff, $Q_{average}$ denotes the mean value of the series of runoff. Next, their deviation from the mean $(K_i\text{-}1)$ is determined. And finally, the plotting of the integral curve by the sequential summary of these deviations is performed:

$$Fi = \frac{\sum (Ki-1)}{Cv} \qquad (4.2)$$

where C_v - variation coefficient. Thus, the residual integral curve is the sequential sum of the deviations of the specific runoff coefficients from the mean annual.

Descriptions of the integral curves of runoff for the groups of rivers are given in Table C.1, Appendix C. This analysis showed that in all groups of rivers the basic visual special features of the integral curves of runoff were similar with the correlation coefficients of the river runoff R> 0.65; if R is from 0.65 to 0.4 - the general form of large cycles coincides, but a certain difference in the cycles with regards to the time or duration is possible. If R<0.4, then the difference becomes more significant. For example, within the boundaries of the sixth group of rivers, from the beginning of 1980 and up to the year 2000 a small decrease is noted in the integral curve of runoff for the rivers of Central Siberia and Far Eastern Russia, while the rivers of Eastern Siberia shows an increase.

From the table, it is clear that the integral curves of the rivers in regions I and II are similar. For region III the difference between these curves is more striking, especially until the middle of the twentieth century. Afterwards, from approximately 1950, the periods of increase and the periods of decrease of the integral curve begin to concur, although a shift is recorded in a couple of years. The integral curves of river runoff in regions III and IV are significantly different. Thus, the period of increase of the integral curve in 1935-36 and up to 1941-43 on the rivers of regions I and II corresponds to the period of decrease for regions III and IV. And the period of decrease (from 1943-44 till 1955-64) corresponds to the period of increase. However, the rivers of region VI have a period of increase of the integral curve in the period from 1935-36 up to 1938-42 and a period of decrease in the period of 1938-43 up to 1954-56. It is the same as for the rivers of regions I and II. The majority of rivers of regions I, II, III and IV have the period of increase of the integral curve from the beginning or from the middle of the 1990s. For some of the rivers of region V this period of increase of the integral curve starts at the beginning of the 1980s and continues until the end of the 1990s. In the same period, most of the rivers of region VI have a period of decrease of the integral curve.

Unfortunately, the period of observations for most of the rivers of region VI is limited to the beginning of the 1990s.

To obtain data about possible time shift in the trends of the integral curves, these curves were compared using the rivers that offered the longest period of observation in each region. Changes in the trend of the integral curves from west to east and from south to north were examined. In the first case, rivers located approximately on the same latitude were chosen. In the second case, rivers located approximately on the same longitude were chosen.

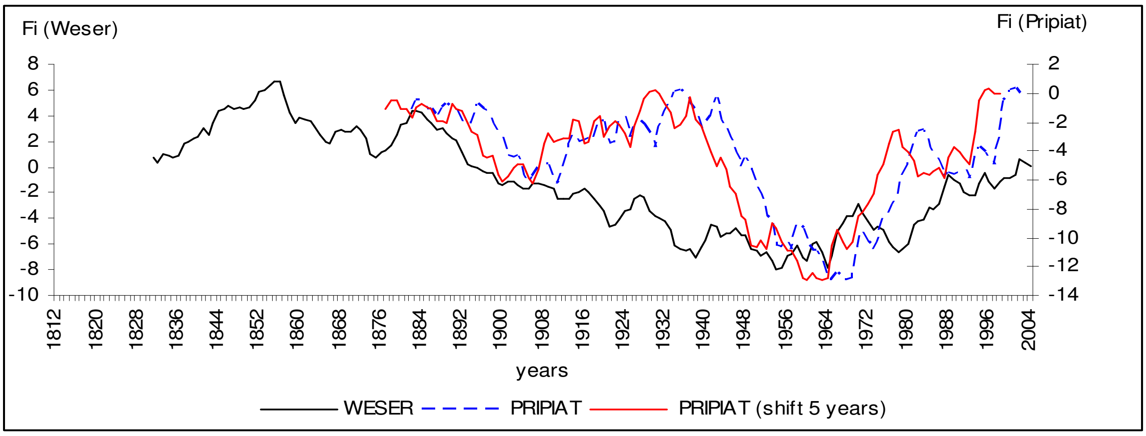
An analysis of the trend in the integral curves of the annual runoff of rivers located approximately at the same latitude, showed that with a distance between the river basins of up to 650-800 km there is no time shift in the trend of the integral curves for the majority of the rivers. A shift from 2 to 5 years occurs when the distance between the river basins is from 800 to 2000 km. If the distance is from 2000 to 3000 km, the shift can be from 4 to 8 years for the different pairs of rivers. If the distance is more than 3000 km, then the shift is from 7 to 16 years and more.

For these particular rivers the visual analysis is confirmed by an increase in the correlation coefficients if the shift in the fluctuations of the integral curves is taken into account. A delay in the fluctuations of the integral curves of river runoff is noted during the propagation from west to the east. For the rivers of Northern and Western Europe (groups II, III and a section of the rivers of group IV) the shifting in the cycles is insignificant. But for the rivers of the Eastern Europe (some of the rivers of groups IV and V) the shift becomes more apparent. This reveals a shift in the trend of the integral curves of the rivers of the Eastern European plain and of the rivers of Northern and Western Europe from the 2 to 5 years (Table 4.1). An example of the trend in the integral curves of the rivers Weser and Pripiat when shifting is taken into account is given in Figure 4.1 (a). The shift between the integral curves of rivers in the Urals, the Belaya, the Elbe and the Weser is as much as 7-8 years.

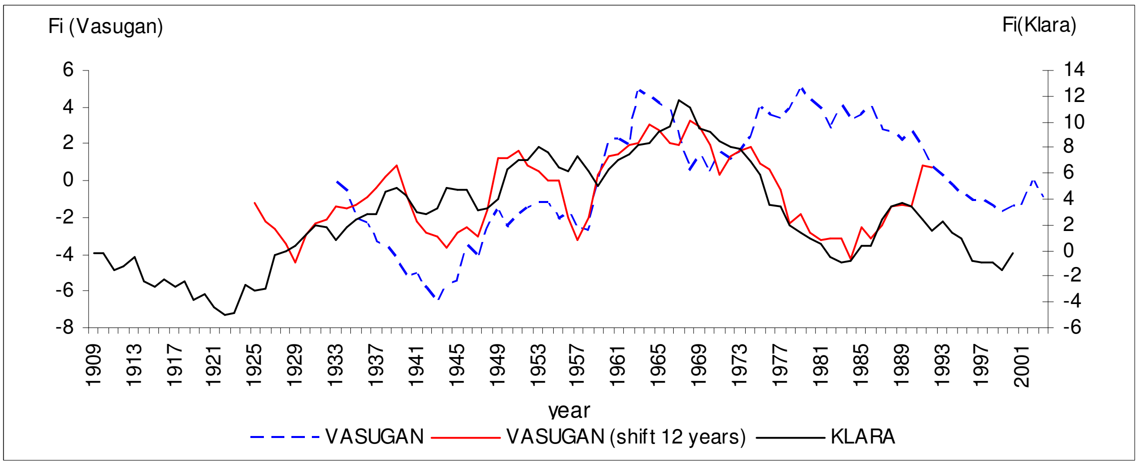
Rivers	R	Shift	R taking shift into account
Inn, Reuss - Southern Bug	0.17, 0.17	2	0.22, 0.23
Elbe-Desna	0.43	5	0.51
Weser – Pripiat	0.52	5	0.58
Vosso, Lagen-Sukhona	0.14,0.48	5,3	0.37,0.58
Weser – Belaya	0.41	8	0.60
Elbe – Ural	0.19	7	0.60
Klara-Vasugan, Bolshoy Pit	-0.02, 0.00	11,13	0.66, 0.45
Lagen – Vasugan	-0.48	12	0.51
Vosso – Chadobets	-0.40	11	0.22
Elbe – Abakan		14	
Onega-Vasugan	0.02	8	0.31
Desna-Tuba	-0.03	4	0.04
Desna-Abakan	0.80	3	0.83
Pripiat-Abakan	0.12	13	0.70
Vasugan-Bolshoy Pit	0.66	2	0.70
Konda-Nyuya	0.17	4	0.40
Bolshoy Pit-Nyuya	0.12	4	0.34

Table 4.1: Cross-correlation coefficients of the integral curves of the annual river runoff (from west to east)

The trend in the integral curves of the rivers of North Asia (some of the rivers of regions IV and VI and the rivers of Western and Central Siberia) shows a shift in relation to the trend in the integral curves of the rivers of Northern and Western Europe (regions II and III) for a period of 11-14 years (Figure 4.1(b), Table 4.1). With respect to the Eastern European rivers, this shifting can be seen to range, for the different pairs of rivers, from 4 to 13 years (Table 4.1). Shifting is observed also in the trend of the integral curves of river runoff inside the sixth region. The increases and decreases in the integral curve of runoff for the rivers of Western Siberia are recorded as 2-4 years on the rivers of Central and East Siberia (Table 4.1).



a)

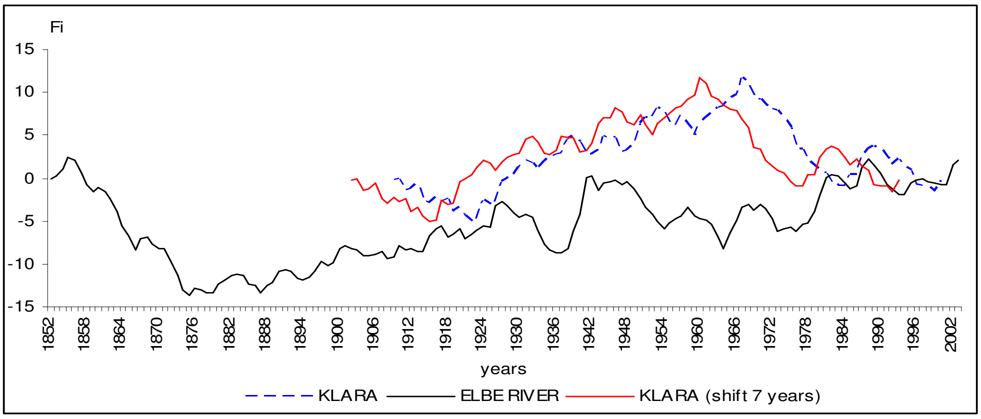


b)

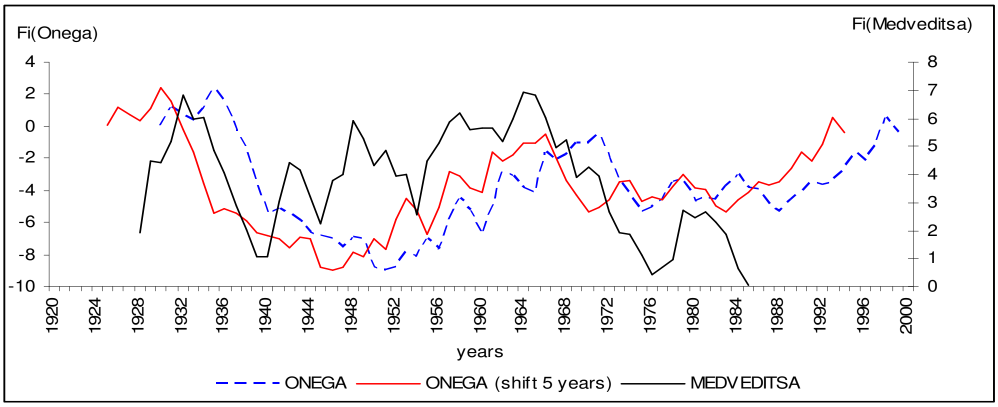
Figure 4.1: The integral curves of the annual river runoff (west to east)

However, it should be noted that such quantitative characteristics of shifting in the trend of the integral curves of annual river runoff are obtained only for separate pairs of rivers. The shift may be absent or may even be observed to be in the opposite direction during displacement. For instance, for rivers located on 37-40^0 northern latitude, the actual direction of shifting could not be determined. The existence of shift in the fluctuations of annual runoff from west to east is indicated in the work of Probst and Tardy as well (Probst and Tardy, 1987). They noted that, the dry period of 1949 in France is observed 6 years later on the river Enisey in Russia. In the work of Pekarova (Pekarova et. al, 2003), a 3 year shift between the extreme water discharges on the rivers Neva and Ob is observed. The shift between the extreme water discharge of the river Ob and that of the river Lena is also of 3 years.

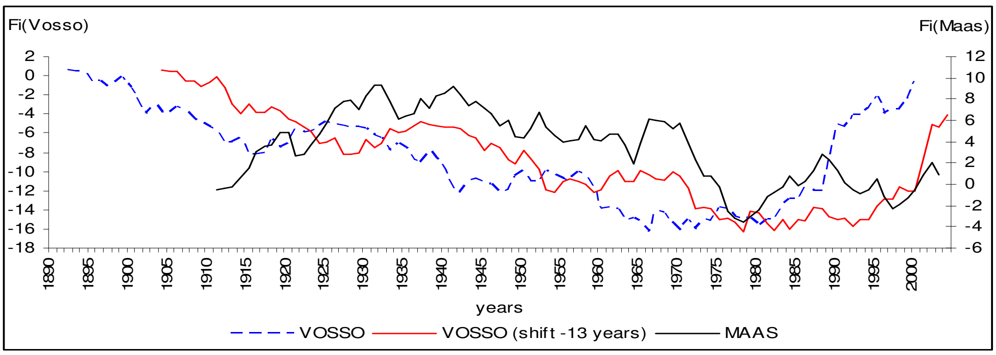
Existence of a shift in the fluctuations of river runoff during the propagation from the south to the north is demonstrated in the work of Probst and Tardy (Probst and Tardy, 1987). For the rivers Senegal (10-15^0 N) and Garonne (40-50^0 N), there is a shift of approximately 9 years. Unfortunately, from the data available, it was impossible to form a clear idea of the characteristic of shift in the direction from south to north. Consecutive observations on the majority of the rivers, located at 30-40^0 N, are lacking. There is no evidence of shifting in the trend of the integral curves of most of the rivers flowing at latitudes 40 and 50^0. With the propagation further to the north (for the 60th latitude) the difference in the trend of the integral curves becomes apparent. For some pairs of rivers the shift is from 5 to 12 years (Table 4.2, Figure 4.2). However, for other pairs the opposite sign may apply (Table 4.2).



a)



b)



c)

Figure 4.2: The integral curves of the annual river runoff (south to north)

The possibility of identifying the presence and quantitative characteristics of the shift (2-3 years or 5-7 years) for different pairs of rivers with approximately identical distances between the river basins seems to depend, in our view, on differences in the duration of the prevailing cycles on the different rivers. For future research it will be interesting to increase the observation period of river runoff by simulation with the help of existing statistical methods (for example the Monte Carlo method) and to compare the shift for cycles of different duration.

Rivers	R	Shift	R taking shift into account
Elbe-Klara	0.03	7	0.17
Pripiat -Vuoksi	0.43	12	0.63
Medveditsa-Onega	0.12	5	0.27
Yu Jiang – Nyuya	-0.17	8	0.40
Maas-Vosso	0.02	-13	0.68
Southern Bug - Tana	0.17	-14	0.41
Nimelen-Bytontay	0.22	-2	0.38

Table 4.2: Cross-correlation coefficients of the integral curves of the annual river runoff (from south to north)

4.2 Fourier analysis

There are various approaches that are used in order to identify the duration of cycles of fluctuations of annual runoff (Van Gelder, 2004). The causes of the varying duration of the cycles are seen to be associated with variations in solar activity and the long-period tide generating force of the moon, ENSO, NAO etc. (Shorthouse & Arnell, 1997; Cluis, 1998; Levin et al, 2001; Labat, 2006; Lucero & Rodriguez, 2002).

The interaction of cycles of varying duration gives rise to new frequency-modulated cycles. For example, an 11-year solar cycle interacting with 18.6-year tidal cycle of the moon forms 26.9 and 6.9-year cycles.

The studies in this report draw upon Fourier spectral analysis and Wavelet transform. The Fourier analysis serves to reveal dominant cycles and their characteristics, while the Wavelet analysis allows us to trace the variation of these cycles (e.g. the change in time) (Benner, 1999; Labat, 2006; Zemtsov, 2004).

The spectral analysis theory of Fourier is described in a large number of references. The duration of the cycles on the various rivers is not expressed with a whole number (integer) for the years. Instead, a fractional number is used, as if it "is spreading" between two adjacent variations, for example from 4.1 to 4.4 years. Later, the duration of cycles is rounded to the integer value, still in years. Because of the limited observational data available for some rivers, cycles lasting more than 21 years were omitted from consideration, just as were omitted high-frequency cycles with a period of less than three years.

Table 4.3 presents data on the length of cycles for all groups of rivers (driving cycles are given in bold). The rivers of Europe and Asia are strongly influenced by 3-5 year cycles, 8-9 year cycles and 12-17 year cycles. However, their intensity varies even within any one group for the different rivers that compose it. The spatial distribution has not only a latitudinal but also a meridional character. Up to 400 N on the rivers of Asia the 3-year cycle has a predominant influence. And the 20-year cycle is prevalent on the rivers of Europe. An exception occurs with the rivers of the eastern part of Spain, which are ruled by 5- year cycles and 8-year cycles. From 45 to 70^0 N the duration of the leading cycle varies from north-west to south-east. 15-16 year cycles are dominant over the rivers of Great Britain and over parts of the rivers of Northern Europe. Cycles of the same duration are observed on the rivers of the northern part of the Scandinavian Peninsula. In the southern part of Scandinavia, in the central part of Western Europe and the western part of Eastern Europe 4, 5 year cycles have a leading influence. This coincides with the data presented in the other papers (Van Gelder et al., 2000; Labat, 2006). The duration of the leading cycles increases from 6, 8 to 16 years on the rivers of southern and south-eastern Europe. The rivers of the Asian part of the continent (the rivers of Siberia and the Far East) are most affected by cycles lasting from 12 to 17 years.

Region	**Duration of the cycles (in years)**	**Comments**
I	3, 4, **5, 8, 20**	For the rivers Ebro, Tevere, Maritsa the driving cycle is a 20 year cycle, for rivers Guadiana, Somes and Olt it is 8 year cycle, and for rivers Guadalquivir, Esla there is 5 year cycle.
II	3, **4**, 5, 7, **10**, **15, 16**	The rivers of Great Britain and Northern Europe (Mosel, Weser, Main) have longer cycles (15, 16 years). Crossing far onto the continent (rivers Elbe, Danube, Bug), we encounter shorter cycles (4-5 years) which dominate.
III	**3, 4, 5,** 6, 7, 8,14, **16**	The rivers of Scandinavia have intense cycles of 3 and 5 years. The river Tana is an exception (16 year cycle). The most powerful cycle on the rivers of Central Europe is 4 year cycle. The 7 year cycle, which is observed on the rivers of Scandinavia, gives way to the 7 year cycle on the rivers of Central Europe.
IV	3,**4**,**6**,7,**8**,11,13-**15,20-21**	The rivers of the southern part of Scandinavia (Clara, Helgea) and the rivers of the north of the European part of Russia (Usa and Pechora) have a powerful cycle of 4 years. The rest of the rivers of this region have leading cycles of longer duration (6 years on the rivers Kyronjoki, Vuoksi, 11 years on the rivers Vym and Iijoki, 15 years on the rivers Vasugan and Ket).
V	4,**5**,**6**,7,8,9,**11**,13,16, **21**	The sufficiently strong influence of the 4 and 5 year cycles is noted on the majority of the rivers of this group. Although, the influence of 8 and 9-year cycles increase for rivers Desna, Southern Bug, Medveditsa Belaya and Ural. The rivers of Ural mountain region have also a 21 year cycle.
VI	**3**, 4, 5, 6, **12-17**	Most of the rivers of this group undergo a strong influence from 3,4 and 6 year cycles. The cycles of 12, 13 and 16 years have a strong influence on the rivers of Western and Central Siberia. 12-13 and 17 year cycles predominate on the rivers of the Eastern Siberia. 11-12 and 14 year cycles are obtained on the rivers of Far East.
VII	**3**,**5**,6,**9**,11	To identify the cycles with the duration of more than 15 years for the rivers of this group is an impossible. For the majority of the rivers of this group the predominant cycles are 3 and 5 year cycles. 6, 9, 11 year cycles also have an effect on river runoff. A 4 year cycle has a strong influence on the runoff of the river Karun.

Table 4.3: Oscillation of the annual river runoff

4.3 Wavelet analysis

In the last decades wavelet analysis has been widely used for analyzing localized variations of power within a time series. It is a powerful alternative to Fourier analyses and one of the main advantages of wavelet analysis is that it allows us to determine not only the frequency (or scale) content of a signal but the temporal variation of this frequency, while the Fourier analysis does not provide any information on temporal variation of the frequencies within the signal. The Fourier analysis determines the frequency content of a signal but not the frequency time-dependence. The application of wavelet analysis in geophysics can be found in the work of Farge (1992), Meyers et. al. (1993), Weng and Lau, (1994), Gu and Philander (1995), Torrence and Compo (1998); Lucero and Rodriguez (1999), Labat et al. (2005).

Torrence and Compo (1998) provide a detailed practical guide and toolkit to wavelet analyses. This report follows their methods. Only the main components and methods of wavelet analysis are described here. The readers are referred to Torence and Compo (1998) and other sources, such as Labat et al. (2005), for a more thorough description of wavelet analysis capabilities.

The wavelet transforms are classified into discrete and continuous wavelet transforms.

The continuous wavelet transform W_n of a discrete sequence of observations x_n is defined as the convolution of x_n with a wavelet $\psi(t)$ scaled (normalized) at wavelet scale *s* and translated in time by *n*:

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi^* \left[\frac{(n'-n)\delta t}{s} \right] \quad (4.3)$$

where the (*) indicates the complex conjugate, *n* is the localized time index, δt is the sampling period, *N* is the number of points in the time series, and the asterisk indicates the complex conjugate (Torence and Compo, 1998). To approximate the continuous wavelet transform, the convolution is done by using the Fourier transform:

$$W_n(s) = \sum_{k=0}^{N-1} \hat{x}_k \hat{\psi}^*(s\omega_k) e^{i\omega_k n \delta t} \quad (4.4)$$

where $\hat{x}_k$ is the Fourier transform of x_n, *k* is the frequency index (0, . . . , N - 1), $\hat{\psi}(s\omega_k)$ is the Fourier transform of the wavelet function at scale *s* and angular frequency ω_k. Wavelet functions can be either orthogonal (such as Daubechies, Haar wavelets) or non-orthogonal (such as Morlet, Paul, Mexican Hat).

Wavelet function

The choice of the wavelet function has a great influence on the results. Wavelet functions which are typically used are outlined in Table 4.4 (Torrenco and Compo, 1994):

Name	$\psi_0(\eta)$	$\widehat{\psi_0}(s\omega)$	e-folding time τ_s	Fourier wavelenght λ
Morlet (ω_0= frequency)	$\pi^{-1/4}e^{i\omega_0\eta}e^{-\eta^2/2}$	$\pi^{-1/4}H(\omega)e^{-(s\omega-\omega_0)^2/2}$	$\sqrt{2}s$	$\frac{4\pi s}{\omega_0+\sqrt{2+\omega_0^2}}$
Paul (*m*= order)	$\frac{2^m i^m m!}{\sqrt{\pi(2m)!}}(1-i\eta)^{-(m+1)}$	$\frac{2^m}{\sqrt{m(2m-1)!}}H(\omega)(s\omega)^m e^{-s\omega}$	$s/\sqrt{2}$	$\frac{4\pi s}{2m+1}$
DOG (*m*= derivative)	$\frac{-1^{m+1}}{\sqrt{\Gamma(m+\frac{1}{2})}}\frac{d^m}{d\eta^m}(e^{-\eta^2/2})$	$\frac{i^m}{\sqrt{\Gamma(m+\frac{1}{2})}}(s\omega)^m e^{-(s\omega)^2/2}$	$\sqrt{2}s$	$\frac{2\pi s}{\sqrt{m+\frac{1}{2}}}$
$\mathrm{H}(\omega)$=Heaviside step function, $\mathrm{H}(\omega)=1\ if\omega>0, \mathrm{H}(\omega)=0\ otherwise.$ DOG= derivative of a Gaussian, *m*=2 is the Marr or Mexican hat wavelet.				

Table 4.4: Three typically used wavelet functions (from Torrence and Compo, 1994)

The transformation of the time series with the help of Morlet wavelet was carried out in this work in order to trace the temporal dynamics of cycles lengths. The Morlet wavelet is commonly used for the analysis of climatic and hydrological series (Lucero of & Rodrigues, 2002; Zemsov, 2004; Labat, 2006). The software provided by Torrence and Compo (1998) was used for calculations.

The longest period of observation on the rivers of 1 group is available on the river Mures (since 1877). On Figure 8 the wavelet image of mid-annual water discharges of this river is presented. The area below the dotted curved line is a cone of influence, outside which the reliability of the results are limited as they are significantly influenced by the lack of observations available (Torrence & Compo, 1998), therefore cycles greater than 16 years were not considered. The black solid contour lines limit a 5% significance value. The other shades of grey in the spectrogram correspond to 25%, 50% and 75% of power.

During the period from the beginning of 1900, prior to the beginning of the 1920s, the influence of 8-12-year cycles and 3-4-year cycles are noticeable. The 4 years cycles are present for practically the whole period of observations (Figure 4.3). From 1945 to 1960, some influence of 12-14-year cycles is also noticeable. From 1910 to 1920 there is an influence from 11-14-years cycles on other rivers of this group. It is revealed that on the majority of the rivers in this group, from the middle of the 1930s to the end of the 1940s and at the beginning of the 1950s, cycles of 4-6 years are present, however the prominence of these cycles alter disappears.

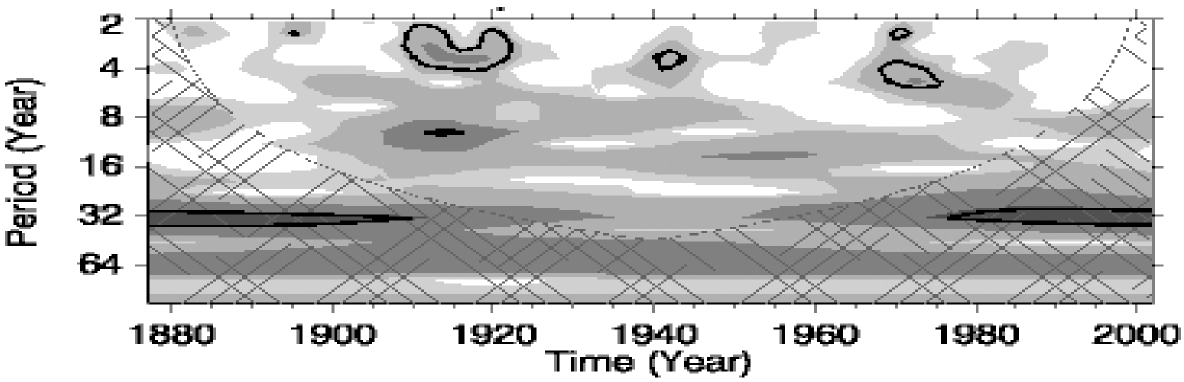


Figure 4.3: Wavelet of the annual water discharges of Mures river

The group of rivers which have the second the longest series of observations are the Elbe, Mai and Weser. For these rivers, the period up to the end of the 18th century is characterized by the impact of the cycles duration, which increases from 4 to 6 years in 1850-1860 and up to 8-12 years and more in the 1890s. At the end of the 18th century and up to 1915-1920 the periodicity on these rivers was weak. In the 1930s, 4-6 year cycles have an impact on the river runoff. The length of cycles increases up to 6-8 in 1980. There is also a visible influence of 12-16 year cycles from the 1920s and until the end of the 1970s and early 1980s.

An example of the wavelet image of the annual runoff of river Main is presented in Figure 4.4. A similar picture was observed on the other European rivers of this group, where monitoring began in the 19th century. For the rivers of Great Britain such as Trent and Tweed, where the monitoring starts in 1959 and 1963, respectively, the picture is different. The periodicity is very powerless there. The river Thames has been under the influence of 3-4 year cycles from 1900 up to 1950. From 1910 to the end of the 1960s, there is also evidence of 10-14 year cycles, changing towards 8-12 year cycles.

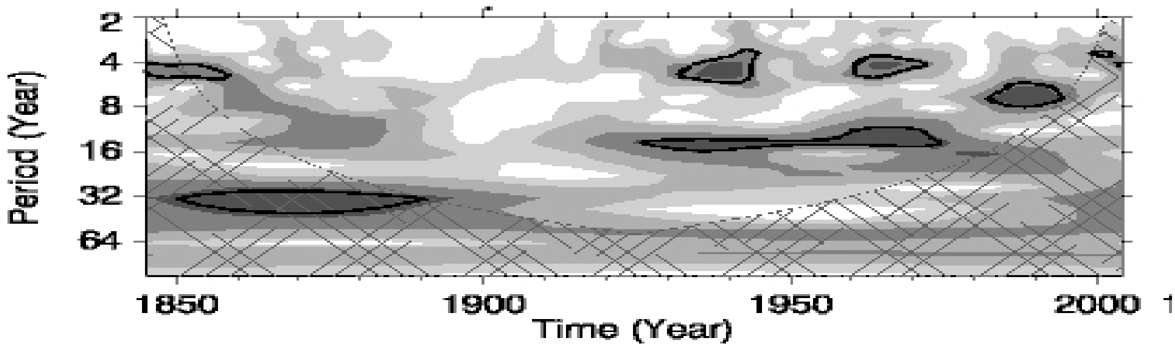


Figure 4.4: Wavelet of the annual water discharges of Main river

In the third group of rivers, the river Inn has the longest series of observations. 3-5 year cycles are observed throughout the full duration of all observations. Up to the end of the 18th century there is also evidence of 6-8 and 12-14 year cycles. From the beginning of the 1900s up to the 1950s, only the influence of 3-5 year cycles was evident. Since the 1950s, the 8-14 year cycles become prominent. Their duration gradually increases up to 14-16 years. From the end of the 1950s until the end of the 1970s, the duration of 3-5 year cycles also increases up to 6 years. At the end of the 1970s, there was an influence of 6-8 year cycles (Figure 4.5). The other rivers of Central Europe (within this group) have cycles in the range of 3-5 years from the 1920s up to the end of the 1970s. In the early 1980s there is also evidence of 3-5 year cycles, which is a reduction in duration from the 6-8 year cycles evident in 1940s. There is also an impact of 14-16 year cycles at the end of the 1930s on the river Reus, and on the rivers Sava and Ron at the end of the 1950s. Since the 1980s there has also been evidence of been 6-8 year cycles. On the rivers of Scandinavia, where data observations are available from the end of the 18th century until the 19th century, there are 3 and 4-5 year cycles which are visible through the entire period of observation. From the beginning/middle of the 1930s until the end of the 1940s these rivers are also influenced by 6-8 year cycles and cycles of 12 and 14-16 years.

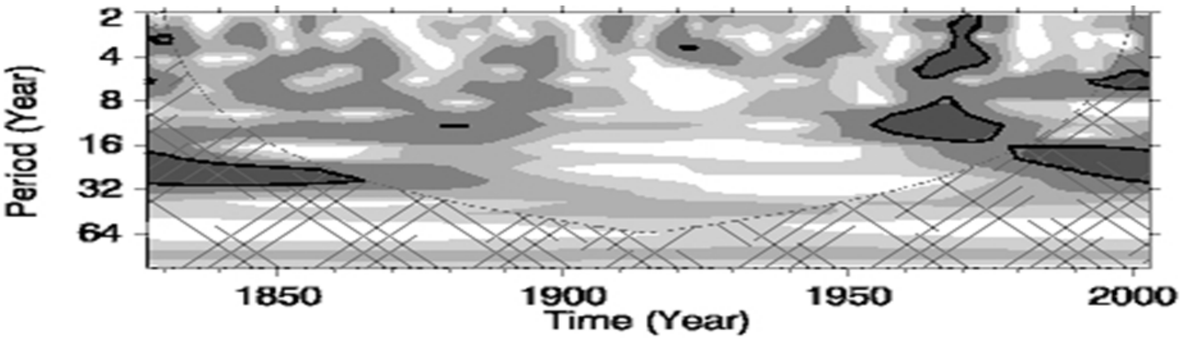
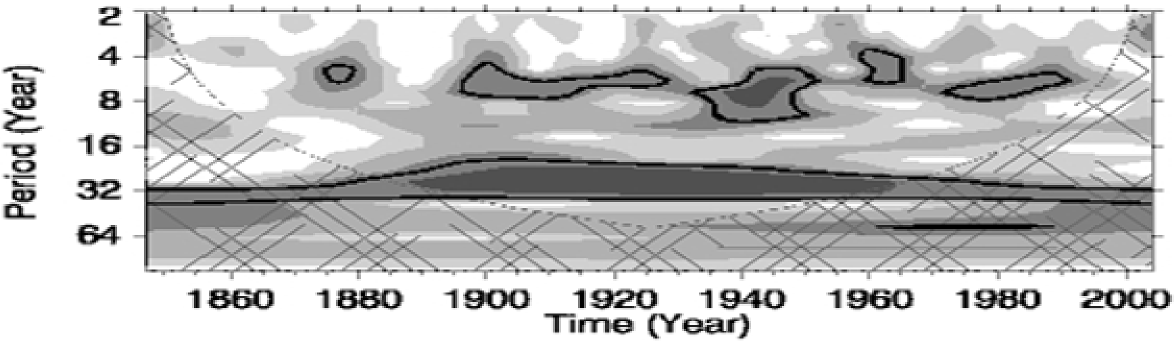
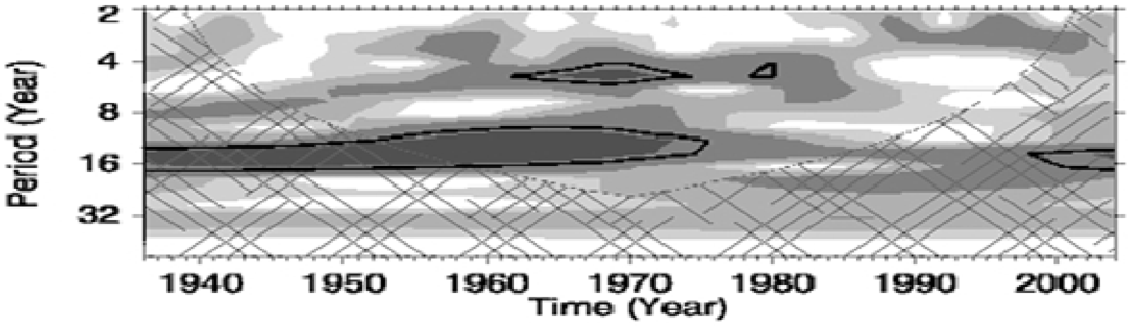


Figure 4.5: Wavelet of the annual water discharges of Inn river

The longest series of observations on the rivers of the fourth group belong to the rivers Vuoksi and Glomma. The river Vuoksi is influenced by very long cycles (28-32 years) during the whole period of the observations. Glomma has the same picture but the influence of these cycles is weaker than for Vuoksi. The impact of short cycles (4-5 and 6- 8 years) on the Vuoksi river runoff is observed during the full observation period, with the exception of the period at the end of the 1930s and 1950s (Figure 4.6, a). 3 and 4-5 years cycles are present in the most of the rivers of this group with the different power. The 1920s and early 1950s are characterised by the influence of 6-8 year cycles for Scandinavian rivers within this group. Rivers such as Iijoki and Kyronjoki are also noticeably influenced by an 11 year cycle that showed its power in the 1940s and 1960s, and in the 1970s on river Iijoki. The observations on the rivers of the North East European Plain of Russia and Western Siberia only began in the 1930s. The impact of the 14-16 year cycle on the river runoff of Western Siberian rivers reduces in the 1970s on the rivers and Ket and Vasugan (Figure 4.6, b), and in the 1960s on the Iset and Konda rivers. At the same time, the 5 and 6-8 year cycles show an increasing influence up to the 1990s before decreasing again. The rivers of the North East European Plain show cycles of 3-4 years. Longer cycles have no significant influence on the river runoff of these rivers.



a)



b)

Figure 4.6: Wavelet of the annual water discharges of rivers Vuoksi (a) and Vasugan (b)

The river Nemunas has the longest observation period of the rivers of the fifth group. There is a noticeable influence of short cycles (4-6 years), which continued up to the end of the 1850s (Figure 4.7). Thereafter, the duration of the cycles increased. By the end of 18th century, the length of cycles had increased to 14-16 years. The 19th century is characterised by the influence of 8-9 year cycles on the river runoff. However, by the middle of 1930s, their impact almost vanished. At this time, there is a strong presence of 20-28 year cycles, which is significant up to the end of the period of observation. However, a distortion can be seen in the determination of the duration of the long cycles from 1970 onwards, as this falls within the cone of influence. On the Pripyat River, where monitoring started at the end of 18th century, in the early 19th century there is a noticeable presence of 5-6 year cycles, whose duration decreased to 4-5 years in the 1930s. Beyond that, their influence vanished and re-appeared again only in the 1970s. The periodicity of 7-9 years which was observed from the 1930s changes to 11 years in the 1950s. The rest of the rivers of this group exhibit cycles of 3-4 years, which, by the end of the 1920s-1930s, increase in duration towards 4 or 5 years, and on some rivers even up to 7-8 years in the 1950s-1970s. After the 1950s-1970s the duration of the cycles is reduced to 3 or 4 years again. Unfortunately, on most of the rivers, the observation period only lasted until the end of 1980s, and therefore it is not possible to talk about this with a high level of confidence. In the middle of the 19th century 9-11 year cycles also showed their influence.

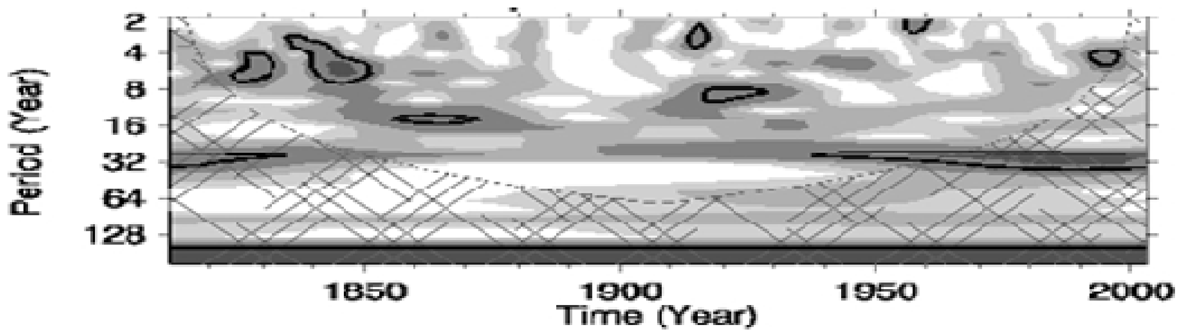


Figure 4.7: Wavelet of the annual water discharges of river Numanas

For the sixth group of rivers, the longest observation period is recorded on the river Bia. In the early 19th century, the influence of 4 year cycles, and later, 8 year cycles were observed. This influence decreased up until the 1920s (Figure 4.8). After the early 1920s, the influence of cycles in 16-19 year range increased before reducing at the end of 1950s. From 1950 and up to the early 1980s, no significant periodicity was evident in the recorded runoff data. In the 1990s, cycles of 6 to 8 years appear to be prominent; however, this cannot be meaningfully taken into consideration because it is in the zone of the cone of influence. For the rivers Tom and Tuba, the influence of 6-7 and 14-16 year cycles also diminished by the end of the 1950s. In the early 1980s 6-7 year periodic cycles appear. The rivers of Srednya Siberia (Kan, Abakan, Chadobets and Pit), where the observations start in the 1940s, are characterised by 16 year cycles of runoff. The duration of the cycles decreased to 13-15 years in the early 1980s and their influence becomes less significant. During the 1980s, no significant cycles could be observed. Most of the other rivers within this group show a similar picture.

For the seventh group, the longest series of observations were recorded on the rivers Kuban and Karun (from the end of the 1910s). The river runoff of Kuban is influenced by 4-5 year cycles. However, it is not significant and is not within the 5% interval relevance (Figure 4.9). The Karun River is influenced by cycles in the region of 3-4 years. For all river basins within this group, 3-5 year cycles were shown to be prominent. Unfortunately, as the series of observations on the rivers in this group is so short, it was not possible to accurately determine the duration of cycles.

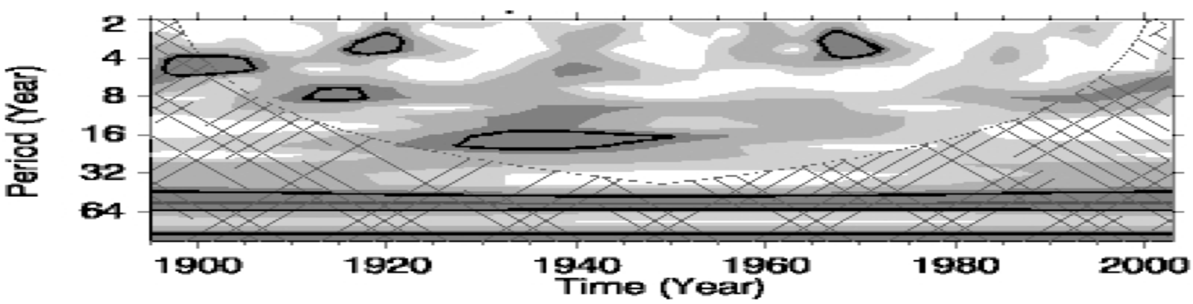


Figure 4.8: Wavelet of the annual water discharges of river Bia

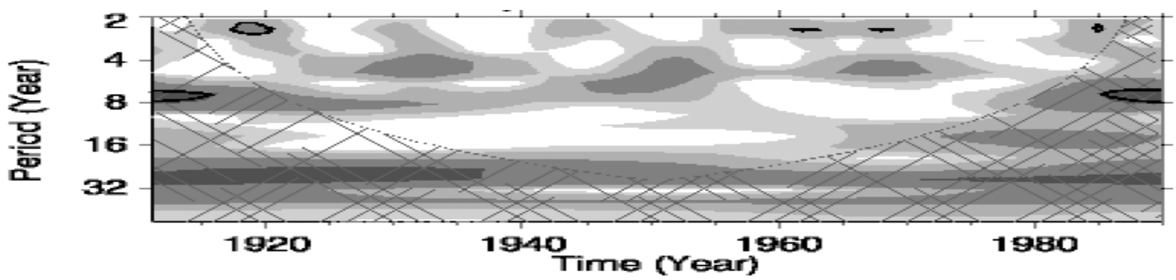


Figure 4.9: Wavelet of the annual water discharges of river Kuban

The wavelet analysis shows that there are changes in the duration of the cycles in the river runoff of all groups. For the rivers of the second and third group, where the observations start in the 18th century, a decrease in the influence of the cycles is observed in the early part of 19th century. The rivers of Great Britain do not follow this trend and changes in the runoff cycles are not apparent in this period. At the beginning of the 19th century, observations were being recorded at the most of the researched rivers. In the 1930s-1940s, changes in the duration of the cycles on most rivers of Eurasia were observed; the rivers of group 2 (except rivers of Great Britain), the rivers of Scandinavia from group 3 and 4 along with the rivers of group 5, 6 and 7. In the 1950s-1960s, there is a change in the fluctuation cycles of the rivers in the South of Europe (group 1), the European rivers of the group 3, and some rivers of the group 7. In the 1970s, changes in cycles were observed for the rivers in group 1, rivers of West Siberia plains from group 4 along with the rivers of group 5 and 6. From 1980 to the 1990s, changes were identified in the rivers within group 2.

5.0 SUMMARY AND CONCLUSION

The INFRARISK project is concerned with the behaviour of critical infrastructure, such as road and rail networks, when subjected to natural hazards such as landslides, floods, earthquakes or a combination of all three. These natural hazards, as well as the behaviour of the infrastructure when the natural hazards occur, vary both spatially and temporally. It is shown in this deliverable that wavelets can be considered as a very suitable and powerful approach to model the temporal and spatial variability at different scales.

Non-stationary time series in geophysics, atmospheric science and environmental engineering, which show temporal and spatial variability at different scales, can be analysed in ‘wavelet space’ in order to identify the main characteristics in time and space. Wavelet analyses are used to understand the space-time cycles of the “loads” on critical infrastructures (precipitation, runoff, earthquake magnitudes, etc).

In order to perform a wavelet analysis, data needs to be provided as time series (not necessarily with fixed time intervals) at multiple (not necessarily equidistant) locations. Typical preparatory work involves zoning of spatial areas, autocorrelation analyses, integral curve analyses, and Fourier analyses. The analysis establishes zones of synchronization or non-synchronization of fluctuations across time and across territory - quantifying possible changes in the fluctuations of for instance water content of rivers – determining any possible phase shift in the cycles, etc.

Wavelet analysis can also use either simulated or real-valued data to understand the space-time cycles of CI’s.

Quantification of the relationship between natural hazards, the environment and critical infrastructure benefits from using spatio-temporal models. Wavelet models help us to understand the space-time cycles of the “loads” on the critical infrastructures (precipitation, runoff, etc). It may point out areas where critical infrastructures are exposed to higher stress levels or periods in the near future with higher stress levels, which can be exploited when designing stress tests for CI’s.

The wavelet analysis in this study has shown that there are changes in the duration of cycles in the river runoff in a set of 7 identified groups (see Figure 2.2). For the rivers of the second and third group, where the observations start in the 18th century, a decrease in the influence of the cycles is observed in the early 19th century. The rivers of Great Britain are exceptional because the changes in the runoff cycles are not observed in this period. In the beginning of the 19th century the observations started at the most of the investigated rivers. In the 1930-1940s, the changes in the duration of cycles of most rivers in Eurasia were observed (the rivers of group 2, except rivers of Great Britain), the rivers of Scandinavia from group 3 and 4, the rivers of group 5, 6 and 7). In the 1950-1960s, there is a change in the fluctuation cycles of the rivers of South Europe (1st group), the European rivers of group 3, and some rivers of group 7. In the 1970s, the changes in cycles were observed for the rivers in group 1, rivers of West Siberia plains from group 4, rivers of group 5 and 6. From the 1980s to the 1990s changes were highlighted on the rivers of group 2 only.

Acknowledgements

We express our thanks to colleagues from Iran, Germany and Russia for their help in obtaining the data.

6.0 REFERENCES

Afanasiev A., 1967. Fluctuation of the hydrometeorological regime on USSR territory. Moscow: Nauka (in Russian), 423.

Aivazian S., Mkhitarian V., 2001. Applied Statistics and Basic Econometrics (2nd edition). Vol. 1: Probability Theory and Applied Statistics, Moscow, UNITY, 656.

Antipov A., Korytnyi L., 1981. Geographical aspects of the hydrological research. Novosibirsk: Nauka (in Russian), 174.

Benner T., 1999 Central England temperatures: long term variability and teleconnections, Int. J. Climatol. 19, 391-403.

Cluis D., 1998. Analysis of long runoff series of selected rivers of Asia-Pacific region in relation with climate change and El Nino effects. Global Runoff Data Center, Federal Institute of Hydrology report No. 21.

Druzhinin I.P., Smaga V.R., Shevnin A.N., 1991. Dynamic of the long-term fluctuations of the river runoff. Moscow:Nauka, 175.

Evstigneev V., Zhuk V., Kalinin G., Nikolskaya N., 1975. Calculation of the river runoff on the base of the generalized likelihood curves. Moscow:Izdatelstvo MGU (in Russian), 125.

Goroshko N.V., Burakov D.A. H.B., 2007. Factors and characteristics of the spatial correlation of the annual runoff of the Upper Ob basin rivers. Meteorology and Hydrology, №1, 101–109.

Hydrometeoizda, 1998. Spatial and temporal variations in the river runoff of the USSR, Leningrad (in Russian), 376.

Iberla K., 1980. Factorial analysis, Moscow (in Russian), 398.

Kalinin G.P., 1968. The problem og the global hydrology Leningrad, Hydrometeoizdat (in Russian), 376.

Kritsky S.H., Menkel M.F., 1981. Hydrological principals of management of the river runoff Moscow: Nauka (in Russian), 255.

Kuchment l.S., Motovilov Yu. G., Nazarov N.A., 1990. Setsativity of the hydrological models, Mocsow: Nauka (in Russian), 143.

Kuzin P., Babkin V., 1979. The Geographical Laws of Hydrologic Regime of Rivers. Hydrometeoizdat, Leningrad (in Russian), 199.

Labat D. (2006) Oscillations in land surface hydrological cycle. Earth and Planetary Science Letters 242, 143-454.

Levin B.V., Savelieva N.I., Semiletov I.P., Chirkov E.B., 2001. Chandler Wobble of pole and its role in the geophysical and hydrometeorological processes. Sbornik: Hydrometeorologycal and biochemical research in Arctic. TOI DVA RAN, Vladivostok (in Russian), 158- 165.

Lubushin A.A., Bolgov M.V., Maksutova M.V, 2006. Wavelet analysis of the long-term fluctuations of the hydrological regime of the Volga, the Don and the Dnieper river basins, Proceedings of the International Scientific Conference: Extreme hydrological events in the Aral and Caspian region. Moscow, 97-100.

Lucero O. and Rodriguez N., 2002. Spatial organization in Europe of decadal and interdecadal fluctuations in annual rainfall, International Journal of Climatology 22, 805-820

Niven E.B., Deutsch C.V., 2012. Calculating a robust correlation coefficient and quantifying its uncertainty, Computers & Geosciences, Volume 40, March 2012, p. 1–9.

Pekarova P., Miklanek P., Pekar J., 2003. Spatial and temporal runoff oscillation analysis of the main rivers of the world during the 19th-20th centuries, J. Hydrol. 274, 62-79.

Probst J., Tardy Y., 1987. Long range streamflow and world continential runoff fluctuations since the beginning of this century. J. Hydrol. 94, 289-311.

Ratkovich D., 1976. Long-term fluctuations of the river runoff. Leningrad: Hydrometeoizdat (in Russian), 256.

Rousseeuw P. J., 1987. Silhouettes: a Graphical Aid to the Interpretation and Validation of Cluster Analysis, Journal of Computational and Applied Mathematics 20, 53-65.

Rozhdestvensky A., Chebotarev A., 1974. Statistical methodsinhydrology). Leningrad: Gidrometeoizdat (in Russian), 424

Shorthouse C., Arnell N.W., 1997. Spatial and temporal variability in European river flows and the North Atlantic Oscillation, Friend’97, Int. Assoc.Hydrol. Sci. Pub. 246, 77-85.

SP 33-101-2003, 2004. Determination of the main hydrological parameters, Moscow (in Russian).
The nature of the long-term fluctuations of the river runoff, 1976. Nauka (in Russian), 335.

"The Times" Comprehensive Atlas of the World 2000 (10th Edition), 2001. Times Books, London

Torrence C. and Compo G., 1998. A Practical Guide to Wavelet Analysis. Bull. Amer. Meteor. Soc., 79, 61-78 http://ion.exelisvis.com/

Van Gelder P., 2004. Statistical estimation methods in hydrological engineering, In: Analysis and stochastic modeling of extreme runoff in Euroasian rivers under conditions of climate change, Pages 11- 57, Proceedings International Scientific Seminar, Irkutsk, 16-23 June 2003 Publishing House of the Institute of Geography, Editors: L.M. Korytny and W.M. Luxemburg, ISBN 5-94797-040-6

Van Gelder P., Kuzmin V., Visser P., 2000. Analysis and statistical forecasting of trends of hydrological processes in climate changes, Proceedings of the International Symposium on Flood Defence, Eds. Frank Toensmann and Mafred Koch, 1, September 20-23, 2000, Kassel, Germany, D13-D22

Van Gelder P., Neykov N., Neytchev Pl., Vrijling J., and Chbab H., 1999. Probability Distributions of Annual Maximum River Discharges in North-Western and Central Europe, TU Delft Report, August 1999.

Vinogradov Yu. B., 1988. Mathematical modelling of the runoff formation. Leningrad: Hydrometeoizdat (in Russian), 312.

Water Resource Series: Daily runoff of the rivers of USSR (in Russian).

Water Resources of USSR, 1966. Vol.18 Far East, (1).Primorie , Leningrad: Hydrometeoizdat (in Russian).

Water Resources of USSR, 1972. Vol. 11, Middle Ural and Ural Hills, (1) Kama, Leningrad: Hydrometeoizdat (in Russian).

Water Resources of USSR, 1972. Vol. 15 Altay and West Siberia. (2): Middle Ob, Leningrad: Hydrometeoizdat (in Russian).

Water Resources of USSR, 1973. Vol. 15 Altay and West Siberia., (3) Lowland Irtish and Lowland Ob, Leningrad: Hydrometeoizdat (in Russian).

Water Resources of USSR, 1973. Vol 16. Angara-Enisye catchment (1): Enisey, Leningrad: Hydrometeoizdat (in Russian)

Williams G., 1961. Cyclical variations in the world-wide hydrological data. Journal of Hydraulic division 6, 71-88.

Zemtsov V.A., 2004 Surface water resources of the Ob river basin: the basic laws and water management problems. Doctors thesis, Tomsk (in Russian), 321.

Zemtsov V.A., Paromov V.V., Savichev O.G., 2000. Changes in the runoff of the major rivers of the South of West Siberia in 20 century. Fundamental problem of water and water resources. Proceedings of the Russian Scientific Conference. Tomsk (in Russian), 21-324.

APPENDIX A – LIST OF RIVERS

River	Gauge	Country	Geographical coordinates of gauge		Period of observation		
			latitudea	longtitud	Starting year	Ending year	Number of years
MARITZA	PLOVDIV	BG	42.15	27.73	1936	1985	49
PRIPIAT	MOZYR	BY	51.97	29.23	1882	2002	120
REUSS	MELLINGEN	CH	47.39	8.25	1904	2003	99
RHONE	CHANCY	CH	46.15	5.97	1904	2003	99
YU JIANG	NANNING	CN	22.80	108.37	1936	1984	48
WU JIANG	GONGTAN	CN	28.90	108.35	1939	1982	43
LUAN HE	LUAN XIAN	CN	39.73	118.75	1929	1983	54
YONGDING	GUANTING	CN	40.23	115.60	1925	1983	58
JING HE	ZHANGJIASHAN	CN	34.63	108.60	1933	1986	53
HAN SHUI	ANKANG	CN	32.68	109.02	1935	1986	51
MORAVA	MORAVICANY	CZ	49.76	16.98	1912	2000	88
INN	WASSERBURG	DE	48.06	12.23	1827	2003	176
WESER	HANN.-MUENDEN	DE	51.43	9.64	1831	2004	173
MAIN	SCHWEINFURT	DE	50.03	10.22	1845	2004	159
ELBE	DRESDEN	DE	51.06	13.74	1852	2001	149
DANUBE	ACHLEITEN	DE	48.58	13.50	1901	2002	101
MOSELLE	COCHEM	DE	50.14	7.17	1901	2004	103
GUADIANA	PUENTE DE PALMAS	ES	38.88	-6.97	1920	1992	72
EBRO	TORTOSA	ES	40.82	0.52	1913	1999	86
ESLA	BRETO	ES	41.88	-5.75	1930	1992	62
GUADALQUIVIR	ALCALA DEL RIO	ES	37.52	-5.98	1913	1992	79
VUOKSI	TAINIONKOSKI	FI	61.22	28.78	1847	2004	157
IIJOKI	RAASAKKA (NEAR THE MOUTH)	FI	65.32	25.43	1911	2004	93
KYRONJOKI	SKATILA (LANSORSUND)	FI	63.13	21.85	1911	2004	93
TRENT	COLWICK	GB	52.95	-1.08	1959	2003	44
TWEED	NORHAM	GB	55.72	-2.16	1963	2003	40
THAMES	KINGSTON	GB	51.80	-0.80	1883	2003	120
NARMADA	GARUDESHW	IN	21.92	73.65	1948	1979	31
DAMODAR	RHONDIA	IN	23.43	87.37	1934	1979	45
KARUN	AHVAZ	IR	31.32	48.67	1894	1985	91
MINAB	BERANTIN	IR	27.40	57.17	1963	1985	22
TIVERE	RIPETTA	IT	41.90	12.43	1921	1997	76
NEMUNAS - NEMAN	SMALININKAI	LT	55.07	22.60	1812	2003	191
MAAS	BORGHAREN	NL	50.87	5.72	1911	2004	93
GLOMMA	ELVERUM	NO	60.88	11.56	1871	2001	130
VOSSO	BULKEN	NO	60.63	6.28	1892	2000	108

LAGEN	LOSNA	NO	61.33	10.28	1896	2000	104
GAULA	HAGA BRU	NO	63.04	10.17	1908	1998	90
KLARA	NYBERGSUND	NO	61.26	12.23	1909	2000	91
TANA (NO, FI)	POLMAK	NO	70.07	28.05	1912	2003	91
BUG	WYSZKOW	PL	52.58	21.45	1920	1986	66
MURES	ARAD	RO	46.16	21.32	1877	2002	125
OLT	CORNET	RO	45.39	24.30	1967	2002	35
SOMES	SATU MARE	RO	47.79	22.85	1925	2002	77
ISET	ISETSKOJE	RU	56.48	65.35	1937	1999	62
KONDA	BOLCHARY	RU	59.82	68.80	1936	1998	62
VITIM	BODAIBO	RU	57.82	114.17	1925	1990	65
NYUYA	KURUM	RU	60.27	114.73	1936	2004	68
ALDAN	TOMMOT	RU	58.97	126.27	1936	1999	63
MARKHA	CUMPURUK	RU	64.14	116.55	1940	1994	54
BYTANTAY	ASAR	RU	68.62	134.12	1937	1999	62
USA	ADZVA	RU	66.55	59.42	1931	1997	66
PECHORA	TROITSKO-PECHORSK	RU	62.72	56.22	1938	1996	58
BELAYA	UFA	RU	54.73	55.93	1878	1995	117
OKA	KALUGA	RU	54.52	36.27	1881	1985	104
URAL	ORENBURG	RU	51.68	55.10	1936	1999	63
SUKHONA	KALIKINO	RU	60.67	45.87	1915	1998	83
ONEGA	KAZAKOVO	RU	62.57	39.83	1930	1999	69
MEDVEDITSA	ARCHEDINSKAIA	RU	49.82	43.17	1928	1985	57
KUBAN	KRASNODSR	RU	45.02	38.98	1911	1990	79
NARYN (NORIN)	UCH-KURGAN	RU	41.17	72.10	1933	1990	57
BIA	BIISK	RU	52.52	85.27	1895	2003	108
TOM	TOMSK	RU	56.50	84.92	1918	2003	85
KET	MAKSIMKIN YAR	RU	58.65	86.82	1937	2003	66
VASUGAN	SREDNY VASUGAN	RU	59.22	78.22	1936	2004	68
ABAKAN	ABAZA	RU	52.65	90.10	1932	2004	72
TUBA	BUGURTAK	RU	53.80	92.87	1911	2004	93
KAN	KANSK	RU	56.22	95.70	1933	2004	71
CHADOBETS	YARKINO	RU	59.13	99.38	1957	2004	47
BOLSHOY PIT	BRIANKA	RU	59.12	93.48	1933	2004	71
VYM	VESLYANA	RU	62.98	50.88	1928	1988	60
SELEMDGA	UST-ULMA	RU	51.95	129.12	1940	2002	62
NIMAM	12 km from the river mouth	RU	51.47	132.65	1947	2002	55
NIMELEN	TIMCHENKO	RU	52.56	136.50	1949	2002	53
HILOK	HILOK	RU	51.36	110.48	1936	2002	66
HELGEA	TOREBRO KRV(POWERSTATION)	SE	56.10	14.13	1908	2003	95
SAVA	RADOVLJIC	SI	46.34	14.17	1945	2002	57
DESNA	CHERNIGOV	UA	51.45	31.35	1885	1985	100
SOUTHERN BUG	ALEKSANDROVKA	UA	47.72	31.18	1914	1985	71

Table A.1: List of rivers

River-gauge	Observation period	Test for means For variances	Critical value	Empirical value	Result
GUADALQUIVIR - ALCALA DEL RIO	1913-1965 1965-1994	Student	1.96	8.08	Hetero
		Fisher	1.66	17.04	Hetero
EBRO - TORTOSA	1913-1977 1977-1999	Student	2.07	4.70	Hetero
		Fisher	1.78	2.33	hetero
VOSSO - BULKEN	1892-1942 1942-2000	Student	1.96	2.49	hetero
		Fisher	-333	1.83	Hetero
KLARA - NYBERGSUND	1909-1968 1968-2000	Student	1.96	2.65	Hetero
		Fisher	-0.88	1.22	Hetero
BUG - WYSZKOW	1920-1963 1963-1986	Student	2.06	3.81	Hetero
		Fisher	1.78	1.83	hetero
MURES - ARAD	1877-1963 1963-2002	Student	1.96	3.02	hetero
		Fisher	-249	1.14	hetero
KARUN - AHVAZ	1917-1947 1947-2004	Student	1.96	2.78	hetero
		Fisher	0.00	1.10	hetero
YOUNDING HE-GUANTING	1925-1952 1952-1983	Student	2.06	3.54	hetero
		Fisher	1.92	2.33	hetero
YUJIANG – NANNING	1936-1952 1952-1983	Student	2.12	3.69	hetero
		Fisher	1.96	1.19	homo

Table A.2: Homogeneity test of annual average water discharge (significant level 5%)

Region	River	High-altitude index (m)	Annual precipitation (mm)	Annual temperature (^0C)	Forest area (%)	Area of lakes and swamps (%)	Area of the land in agricultural use (%)	Density of population
1	Gaudiana, Ebro, Esla,Guadalquiviri, Mures, Olt, Somes, Maritsa, Tivere	1100-1700 (Gaudiana -655; Tivere -326)	800-1300	+7-+20	0- 37	0-3	60	20-200
2	Trent, Tweed, Thames, Maas, Weser, Main, Elbe, Danube, Moselle, Morava, Bug	150-750	800-1450	+10-+15 (Maas-5)	0-30	0-3	70-90 (Trent, Tweed, Thames -15-55)	100-250
3	Inn, Reuss, Rhone, Sava, Vosso, Lagen, Gaula, Tana	1050-1750 (Tana 550)	1200 - 2500	-2-+10	20-60	0-30	0-30	2-300
4	Glomma, Clara, Helgea, Vuoksi, Iijoki, Kyronjoki, Usa, Pechora, Vym, Iset, Konda, Ket, Vasugan	50-100 (Glomma -1240, Klara 900, Usa-755, Iset-675)	600-1000	-5-+5 (Helgea -+10)	50-90 (Usa -5)	3-10 (Konda -50, Vasugan -40)	0-20	2-15
5	Nemunas, Pripiat, Southern Bug, Desna, Belaya, Oka, Ural, Sukhona, Onega, Medveditsa	90-860	500-900	+2-+10	0-30	0-10	55-90	10-100
6	Bia, Tom, Chadobets, Bolshoy Pit, Kan, Tuba, Abakan, Vitim, Nyuya, Aldan, Markha, Bytantay, Selemdga, Nimam, Nimelen, Hilok	980-1790 (rivers of Central Siberian Plato 200-600)	300-700 (Far East – 700-1000)	-10-+2	40-90 (Bytantay – 5)	0-3	0-20	1-10
7	Kuban, Minab, Karun, Naryn, Narmada,Damodar, Yu Jiang, Wu Jiang, Luan He, Youngding, Jing He Han Shui.	From 400-600 on the rivers of India to 2100-3950 on the rivers of Iran and Russia	200-300 to 2000	+5-+27	0-50	0-1	10-80	50-300 (Naryn -20)

Table A.3: Geographical and climate characteristic of the regions

APPENDIX B – CORRELATION COEFFICIENTS OF ANNUAL RIVER RUNOFF

River	Ebro			Maas			Inn			Nemunas			Vasugan			Tuba			Karun		
period	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000	1965-1985	1950-1990	1940-2000
ESLA	0.65	0.72		0.20	0.14		0.01	0.06		0.18	0.06		0.43	0.42		0.39	0.35		-0.15	-0.35	
GUADIANA	0.62	0.46		0.23	0.04		0.21	0.06		0.09	-0.11		0.50	0.32		0.49	0.23		-0.10	-0.33	
UADALQUIVIR	0.70	0.66		0.15	0.10		0.10	0.03		-0.03	0.23		0.48	0.26		0.40	0.13		-0.07	-0.31	
EBRO				0.04	0.04	0.08	-0.08	-0.04	-0.05	-0.23	-0.19	-0.13	0.25	0.24	0.15	0.21	0.19	0.07	-0.09	-0.23	-0.18
TWEED	0.06			0.68			0.51			0.48			-0.37			0.02			-0.22		
TRENT	0.34			0.81			0.52			0.33			-0.17			0.34			-0.23		
THAMES	0.39	0.41	0.42	0.35	0.39	0.43	0.34	0.34	0.29	0.37	0.27	0.26	-0.24	-0.05	-0.05	-0.19	0.05	0.16	-0.30	-0.29	-0.21
RHONE	-0.17	-0.03	-0.01	0.71	0.68	0.68	0.70	0.64	0.63	0.75	0.54	0.46	-0.15	-0.15	-0.20	0.24	0.32	0.13	-0.28	-0.19	-0.23
MAAS	0.04	0.04	0.08				0.72	0.64	0.66	0.44	0.43	0.40	-0.13	-0.18	-0.17	0.33	0.38	0.26	-0.33	-0.22	-0.25
MOSELLE	-0.03	-0.13	-0.05	0.91	0.88	0.90	0.66	0.59	0.63	0.56	0.41	0.34	-0.09	-0.17	-0.19	0.17	0.28	0.24	-0.27	-0.15	-0.23
REUSS	-0.04	-0.03	0.00	0.72	0.67	0.68	0.88	0.86	0.84	0.51	0.42	0.33	-0.15	-0.12	-0.16	0.34	0.42	0.13	-0.37	-0.17	-0.18
VOSSO	-0.34	-0.55	-0.50	-0.16	-0.15	-0.07	0.03	-0.16	-0.02	0.02	0.07	0.00	-0.10	-0.25	-0.27	-0.40	-0.48	-0.11	-0.33	-0.02	0.02
WESER	-0.01	-0.14	-0.03	0.92	0.84	0.84	0.67	0.60	0.55	0.31	0.30	0.38	-0.15	-0.10	-0.08	0.21	0.34	0.34	-0.36	-0.18	-0.20
MAIN	0.03	-0.16	-0.02	0.93	0.84	0.80	0.76	0.66	0.60	0.45	0.31	0.33	-0.11	-0.17	-0.08	0.26	0.36	0.24	-0.31	-0.09	-0.15
GAULA	-0.41	-0.38	-0.32	-0.20	-0.07	-0.06	-0.09	-0.06	0.02	-0.35	-0.06	-0.10	0.04	0.04	-0.02	-0.12	-0.11	-0.04	-0.21	-0.11	-0.01
LAGEN	-0.20	-0.26	-0.27	0.02	0.02	0.09	-0.03	-0.08	0.11	0.08	0.16	0.05	-0.11	-0.12	-0.11	-0.31	-0.35	-0.06	-0.24	-0.03	0.04
GLOMMA	-0.24	-0.06	-0.10	0.26	0.27	0.26	0.37	0.20	0.18	0.15	0.18	0.17	-0.30	-0.17	-0.16	0.15	0.01	-0.08	-0.64	-0.29	-0.18
KLARA	-0.07	0.07	0.01	0.40	0.29	0.28	0.47	0.23	0.26	0.09	0.14	0.08	-0.29	-0.13	-0.12	0.28	0.06	-0.06	-0.68	-0.33	-0.19
HELGEA	-0.23	-0.17	-0.23	0.64	0.57	0.51	0.59	0.45	0.46	0.53	0.45	0.46	-0.22	-0.18	-0.19	0.15	0.16	0.02	-0.55	-0.22	-0.10
INN	-0.08	-0.04	-0.05	0.72	0.64	0.66				0.53	0.39	0.26	-0.17	-0.07	-0.07	0.41	0.48	0.01	-0.50	-0.28	-0.31
TEVERE	0.25	0.48	0.51	0.43	0.22	0.21	0.17	0.11	0.06	0.26	0.01	0.01	0.10	0.22	0.22	0.28	0.22	0.08	0.34	-0.03	-0.13
ELBE	-0.05	-0.24	-0.02	0.72	0.63	0.57	0.81	0.74	0.56	0.58	0.38	0.34	-0.33	-0.17	-0.05	0.12	0.30	0.18	-0.14	-0.05	-0.07
DANUBE	-0.06	-0.16	-0.08	0.80	0.69	0.70	0.96	0.93	0.89	0.61	0.37	0.31	-0.13	-0.08	-0.03	0.34	0.45	0.11	-0.40	-0.19	-0.21
SAVA	0.47	0.54	0.50	0.25	0.27	0.23	0.28	0.25	0.17	-0.11	0.10	-0.05	-0.10	0.10	0.09	0.44	0.31	0.05	-0.15	-0.30	-0.39
MORAVA	0.07	-0.19	-0.08	0.47	0.48	0.47	0.71	0.66	0.55	0.27	0.27	0.22	-0.40	-0.26	-0.15	0.15	0.26	0.09	-0.33	-0.18	-0.20
TANA	-0.23	-0.11	-0.19	0.46	0.22	0.21	0.29	0.15	0.24	0.22	-0.14	-0.25	-0.54	-0.47	-0.37	-0.41	-0.13	-0.19	-0.34	-0.28	-0.20
IIJOKI	-0.11	-0.11	-0.22	0.36	0.18	0.14	0.48	0.31	0.24	-0.02	-0.08	-0.13	-0.24	-0.38	-0.33	-0.08	-0.01	-0.26	-0.54	-0.19	-0.10
KYRONJOKI	0.09	0.01	-0.08	0.28	0.20	0.18	0.18	0.13	0.18	0.12	0.05	-0.02	-0.40	-0.34	-0.29	-0.41	-0.24	-0.09	-0.31	0.05	0.03
VUOKSI	-0.34	-0.34	-0.34	0.22	0.25	0.20	0.17	0.21	0.21	0.16	0.28	0.21	-0.25	-0.35	-0.32	-0.33	-0.13	-0.10	-0.15	-0.01	-0.01
NEMUNAS	-0.23	-0.19	-0.13	0.44	0.43	0.40	0.53	0.39	0.26				-0.02	0.01	0.03	0.03	-0.05	-0.06	-0.14	-0.12	0.00
BUG	0.21			0.13			0.16			0.15			0.18			0.30			0.06		
SOMES	0.14	-0.17	-0.05	0.43	0.33	0.37	0.57	0.51	0.43	0.71	0.45	0.34	0.12	0.10	0.13	0.23	0.20	0.05	-0.04	-0.10	-0.13
MURES	-0.11	-0.16	-0.08	0.20	0.12	0.19	0.43	0.45	0.40	0.58	0.20	0.14	0.27	0.22	0.24	0.18	0.25	0.05	0.08	0.06	-0.05
OLT	-0.03			0.33			0.36			0.48			0.17			0.33			0.13		
MARITZA	0.04			-0.19			-0.14			-0.28			-0.02			0.22			0.35		
PRIPIAT	0.00	-0.17	-0.20	0.11	0.12	0.22	0.44	0.33	0.34	0.53	0.36	0.25	0.35	0.19	0.21	0.08	0.05	0.04	-0.01	-0.06	-0.15
DESNA	-0.14			0.41			0.36			0.61			0.22			0.14			-0.26		
SOUTHERN BUG	-0.09			0.22			0.15			0.57			0.13			0.15			0.16		
ONEGA	0.31	0.01	-0.05	0.37	0.24	0.22	0.07	0.00	-0.01	-0.10	0.03	0.04	0.06	-0.14	-0.14	0.02	0.01	0.14	-0.08	-0.07	-0.13
OKA	-0.10			0.40			0.49			0.69			0.16			0.21			-0.30		
KUBAN	0.11	0.34		0.05	0.07		0.31	0.17		0.01	0.05		-0.56	-0.35		-0.09	-0.07		-0.10	-0.13	
SUKHONA	0.23	-0.05	-0.12	0.35	0.26	0.21	-0.01	-0.05	-0.08	0.21	0.21	0.14	-0.14	-0.21	-0.17	-0.08	0.03	0.08	0.29	0.16	0.02
MEDVEDITSA	0.08			0.25			0.39			0.65			0.13			-0.14			-0.21		
VYM	-0.30	-0.23		0.30	0.20		-0.08	-0.09		-0.28	-0.11		0.05	-0.12		0.12	0.06		0.00	-0.01	
USA	-0.01	-0.19	-0.15	0.15	0.02	0.10	0.24	0.11	0.13	0.33	0.25	0.20	-0.21	0.16	0.07	0.00	-0.07	0.00	-0.08	-0.02	-0.05
PECHORA	0.33	-0.19	-0.21	0.28	0.16	0.18	0.07	-0.02	0.03	0.03	0.01	0.01	0.24	0.13	0.09	0.12	0.05	0.10	-0.15	-0.08	-0.12
BELAYA	0.21	-0.27	-0.21	0.27	0.04	-0.01	-0.10	-0.25	-0.26	0.11	0.01	0.12	0.55	0.23	0.26	0.24	-0.11	0.11	-0.15	-0.19	-0.14
URAL	-0.03	-0.14	-0.07	0.11	0.06	0.02	0.03	-0.05	-0.11	0.24	0.04	0.15	0.47	0.33	0.31	0.17	0.05	0.23	-0.04	-0.02	0.01
KARUN	-0.09	-0.23	-0.18	-0.33	-0.22	-0.25	-0.50	-0.28	-0.31	-0.14	-0.12	0.00	0.01	-0.06	-0.06	-0.16	-0.06	0.01	0.55		
MINUB	-0.19			-0.32			-0.13			-0.03			-0.29			-0.19			-0.19	-0.15	-0.07
ISET	0.28	-0.05	-0.11	0.07	0.16	0.11	-0.09	-0.02	-0.01	0.11	0.04	0.18	0.53	0.31	0.26	0.14	0.13	0.10	0.14	0.16	0.03
KONDA (TRIB. IRTYSH)	0.26	-0.10	-0.17	0.01	0.03	-0.02	-0.15	-0.10	-0.11	0.18	0.13	0.02	0.64	0.47	0.41	0.13	0.05	-0.09	0.05	0.04	
ARYN (NORIN)	0.16	0.33		0.10	-0.02		-0.15	-0.14		-0.41	-0.17		0.18	0.07		0.22	0.10		0.01		
NARMADA	-0.31			-0.63			-0.41			-0.28			0.29			-0.02			-0.30		
DAMODAR	-0.22			-0.47			-0.29			-0.03			-0.04			-0.43			0.01	-0.06	-0.06
VASUGAN	0.25	0.24	0.15	-0.13	-0.18	-0.17	-0.17	-0.07	-0.07	-0.02	0.01	0.03				0.40	0.31	0.18	-0.28	-0.38	-0.32
KET	0.47	0.60	0.39	-0.20	-0.09	-0.06	-0.23	-0.17	-0.17	-0.17	-0.11	-0.05	0.59	0.61	0.51	0.39	0.31	0.26	-0.13	-0.03	-0.02
TOM	0.53	0.23	0.21	-0.10	-0.07	0.04	-0.20	-0.13	-0.08	-0.28	-0.24	-0.13	0.66	0.55	0.42	0.54	0.45	0.68	0.04	0.08	0.01
BIA	0.20	-0.02	0.07	0.01	0.22	0.26	-0.24	-0.04	0.01	-0.41	-0.10	-0.06	0.38	0.31	0.18	0.42	0.44	-0.02	0.16	-0.09	-0.02
PIT	0.20	0.49	0.34	-0.29	-0.27	-0.17	-0.24	-0.26	-0.13	0.03	-0.11	-0.01	0.62	0.44	0.38	0.11	0.02	-0.01	0.02	-0.06	-0.09
CHADOBETS	-0.04	0.24	0.24	0.07	0.04	0.06	0.05	0.02	0.07	0.16	0.08	0.11	0.08	0.08	0.12	0.19	0.18	0.34	-0.16	-0.06	-0.10
KAN	0.10	0.08	0.05	0.23	0.31	0.34	0.39	0.47	0.36	-0.09	-0.06	-0.04	0.15	0.07	0.00	0.84	0.81	0.54	-0.16	-0.06	-0.08
TUBA	0.21	0.19	0.19	0.33	0.38	0.34	0.41	0.48	0.33	0.03	-0.05	-0.08	0.40	0.31	0.14				0.08	0.11	-0.01
ABAKAN	0.07	-0.11	0.00	0.09	0.21	0.22	-0.15	0.03	0.02	-0.26	0.00	-0.01	0.22	0.16	0.18	0.33	0.41	0.75	-0.35	-0.24	
MARKHA	-0.02	0.08		0.20	0.26		0.45	0.21		0.19	0.10		-0.24	-0.27		0.20	0.08		0.10	0.01	
NYUYA	-0.20	0.05		-0.01	0.00		-0.07	-0.15		0.39	0.30		-0.03	-0.02		-0.12	-0.15		-0.24	-0.27	
VITIM	-0.46	-0.08		0.14	0.13		0.05	0.01		0.24	0.06		0.08	0.10		-0.13	-0.10		-0.29	-0.26	
JING HE	-0.25	-0.24		0.23	-0.02		0.35	0.11		-0.11	-0.13		0.04	-0.02		0.17	-0.03		-0.04	-0.17	
AN SHUI (HAN CHIANG)	-0.56	-0.19		0.28	0.16		0.12	0.05		0.24	0.00		-0.12	-0.21		-0.30	-0.20		-0.02		
WU JIANG	-0.17			-0.29			-0.10			-0.14			-0.21			-0.10			-0.26		
YUJIANG	0.06			-0.11			-0.05			0.24			0.09			-0.20			-0.30		
OUNDING HE	0.14			0.36			0.45			0.22			0.07			0.12			0.00		
LUAN HE	0.49			-0.18			-0.08			-0.13			0.27			0.13			0.11	-0.12	-0.05

ALDAN	0.06	0.24	0.08	0.14	0.20	0.05	-0.03	-0.03	-0.05	0.29	0.23	0.05	-0.01	-0.04	-0.01	-0.34	-0.20	-0.17	-0.07	0.06	0.11
BYTANTAY	0.13	0.17	0.15	-0.14	0.05	-0.10	-0.13	-0.05	-0.12	0.12	0.06	-0.05	0.19	0.12	0.05	0.15	0.23	-0.02	0.08	-0.05	-0.02
SELEMDGA	0.09	0.10	0.15	-0.14	-0.15	-0.05	-0.25	-0.19	-0.14	-0.02	-0.02	0.01	0.08	0.15	0.01	0.18	0.09	0.22	0.17	-0.04	-0.12
NIMAM	0.13	0.01	0.03	-0.24	-0.11	-0.07	-0.27	-0.14	-0.09	-0.07	0.01	0.05	0.14	0.25	0.20	-0.02	0.03	0.02	0.11	0.01	0.01
NIMELEN	0.24	0.10	0.11	-0.30	-0.25	-0.16	-0.27	-0.20	-0.14	-0.14	-0.10	-0.04	0.13	0.16	0.00	0.28	0.12	0.26	-0.09		
HILOK	0.08			-0.15			-0.36			-0.35			0.33			-0.05			0.55		

Table B.1: Correlation coefficients of the annual river runoff

APPENDIX C – INTEGRAL CURVES OF RUNOFF

Region:river	Period of increase of integral curve	Period of decrease of integral curve	Stable period of integral curve	Comments
I: Gaudiana, Ebro, Esla, Guadalquiviri, Mures, Olt, Somes, Maritsa, Tivere	from 1911 to 1916-20 (Mures, Ebro) from 1935 to 1941-43 from 1958-59 to1966-68 from 1975-76 to 1979-82 from 1996 to 2002	from 1880 to1911 (Mures) from 1943-44 to1955-58 from 1970-72 to 1975 from 1980-83 to 1996	from 1917-21 to 1932-34	For the most of the rivers the observations start from 1920's and end in 1990's. The observation starts early only on the river Mures (1877 year). The periods of increase and decrease of integral curve of this river are differed from those recoded for the same periods on others rivers, although, at some points the inflections are the same.
II: Trent, Tweed, Thames, Maas, Weser, Main, Elbe, Danube, Moselle, Morava, Bug	from 1832 to 1855-56 from 1875-76 to 1883 (Weser, Main) from 1876 to1927 (Elbe) from 1922 to1928-32 from 1935-36 to1941-42 from 1965 to1970 from 1980 to1988 from 1994-99 to 2002	from 1856 to1874-75 from 1884 to 1921(Weser, Main) from 1928-32 to1934-35 from 1941-48 to 1964 from 1970 to 1977-79 from 1989 to 1993-98		River Bug has a different period of increase and decrease of integral curve - although, the main points of the inflections of the curve coincide with similar points for the other rivers.
III: Inn, Reuss, Rhone, Sava, Vosso, Lagen, Gaula, Tana	from 1849 to 1855 (Inn) from 1874 to1879 (Inn) from 1888 to 1892 (Inn) from 1909 to 1933-	from 1831 to 1842 (Inn) from 1855 to1874 (Inn) from 1879 to 1887 (Inn) from 1892 to 1895 (Inn)	from 1843 to 1848 (Inn) from 1896 to 1908 (Inn) from 1921 to 1945 (Inn)	The river Vosso has an integral curve which is different from the other curves. For example, there is a stable periods of curve from 1940 to 1958

	39 (Inn по 1920) from 1959-65 to 1968-69 from 1976 to 1980-83 (to 1990 Lagen, to 2003 Rhone) from 1992-98 to 2002	from 1892-98 to 1908 (Reuss, Rhone, Sava) from 1933-40 to 1942-50 from 1969-70 to 1973-76 from 1981-84 to 1992-98	from 1942-50 to 1958-64	and from 1966 to 1980. But the main points of the infections of the curve do not differ from similar points on the others curves.
IV: Glomma, Clara, Helgea, Vuoksi, Iijoki, Kyronjoki, Usa, Pechora, Vym, Iset, Konda, Ket, Vasugan	from 1860 to 1879 (Glomma,Vuoksi) from 1897 to 1906 (Glomma,Vuoksi) from 1918-23 to 1931-39 from 1940 to 1944-48 (Iset, Vym) from 1947-49 to 1953-57 from 1960-61 to 1967-68 from 1965-69 to 1983(Usa), to 1997 (Pechora, Konda) from the beginning of 80's to the begginig of 90's. Beginning 90's – end of 90's (Usa, Pechora, Vym, Iset, Konda, Ket, Vasugan)	from 1849 to 1859 (Vuoksi) from 1907 to 1917-22 from 1932-40 to 1946-48 from 1954-58 to 1959-60 (to 80) from 1949-50 to 1964-68 (Usa, Pechora, Vym, Iset, Konda, Ket, Vasugan) 1968-69 and up to beginning of 80's Beginning of the 80's – beginning of 90's (Usa, Iset)	from 1990 to 2002 with a small decrease	The trend of the integral curves of the rivers of the north of East-European and West Siberian plans differs from the trend of the integral curves of the Scandinavia rivers.
V: Nemunas, Pripiat, Southern Bug,Desna,Belaya, Oka,Ural,Sukhona, Onega, Medveditsa	from 1876 to 1886-89 from 1922-25 up to 1934-36 from 1940-41 up to 1962-64 from 1978-82 to 2002	from 1935-37 to 1939-40 from 1963-65 to 1977-82	from 1812 to 1876 (Nemunas) from 1887-90 to 1921-24 from 1937 to 1962 (Nemunas)	The increase of the integral curve of the river Nemunas since the beginning of 1980's is less marked and there is even a certain decrease observed from 1990.
VI: Bia, Tom, Chadobets, Bolshoy Pit, Kan, Tuba, Abakan, Vitim, Nyuya, Aldan, Markha, Bytantay, Selemdga, Nimam, Nimelen,	from 1911 to1926-30 from 1935-36 to 1938-42 from 1957 to 1961-64 from 1962-65 to 1976-79(Tom,	from 1895 to 1910 (Bia) from 1930 to 1934-35 from 1939-43 to 1954-56 (up to 1968 Tom, Vitim to 1979) from 1962-65 to		The trend of the integral curves of the rivers of this region becomes quite distinct in the 1960's.

Hilok	Chadobets, Bolshoy Pit, Kan, Tuba, Abakan, Vitim), and Bia up to 1995 from 1970-76 to 1995 (Nyuya, Aldan to 1999, Markha, Bytantay, Selemdga, Nimam, Nimelen, Hilok)	1969-75 (Nyuya, Aldan, Markha, Bytantay, Selemdga, Nimam, Nimelen, Hilok) from 1977-80 to 2002 (Tom, Chadobets, Bolshoy Pit, Kan, Tuba, Abakan) 1995-2000 (Hilok, Nimam, Nimelen, Selemdga, Bytantay)		
VII: Kuban, Minab, Karun, Naryn, Narmada, Damodar, Yu Jiang, Wu Jiang, Luan He, Youngding, Jing He, Han Shui	from 1913 to 1917(Kuban) from 1930 to 1968 (Kuban), до 1973 Naryn from 1945-50 to 1953-62 (59 and 62 on Luan He and Youngding) from 1987 to 1990 (Kuban and Naryn)	from 1928 to 1929 (Kuban) from 1954-63 to 1967-73, and to 1983 on Luan He and Youngding 1968-74 to 1986 (Kuban and Naryn) from 1980 to 2002 (Karun)	from 1918 to 1927 (Kuban) from 1968-74 to 1980 with a small decrease	The rivers of this region have the shortest period of observation. Therefore, it is difficult to obtain a complete picture of the trend of the integral curves.

Table C.1: Characteristic of integral curve of the annual runoff