Article ID: 1001-6791 (1999) 03-0219-16

World Water Resources and Water Use: Modern Assessment and Outlook for Future°

I. A. Shiklomanov

(State Hydrological Institute, St. Petersburg, Russia)

Abstract: During 1990- 1996 the scientists of the State Hydrological Institute, St. Petersburg, under the scientific guidance of the author of this article, made a new combined assessment of the world water resources, water use and water availability in the dynamics including a forecast for a remote future. The article gives in brief some new quantitative data on the dynamics of renewable water resources of continents. Physiographic and economic regions and selected countries of the world which are generalized from the world hydrological network data. The values of the global water use for the needs of population, industry and agriculture are given as well as the value of the water availability in the dynamics for the current century and for the future before 2010- 2025. The analysis of long-term trends of the world water resources, water use and water availability changes has been made depending on the climatic factors and socio-economic conditions. It is planned to publish all the results of these studies as a monograph "World Water Resources at the Beginning of XXI Century" in 1999, Cambridge, University Press.

Key words: world water resources; water use; water availability; assessment; outlook

CLC number: TV21 **Document code**: A

1 Introduction

Data on Earth's total river runoff, as a major component of the global hydrological cycle and basic characteristic of renewable fresh water resources, are cited in many studies published since the end of past century in different countries of the world. For the past 30 years the results of global estimations have been published with different extent of comprehensiveness in (Nace, 1967; Lvovitch, 1974; World Water Balance…, 1974; Baumgartner and Reichel, 1975, Berner and berner, 1987) as well as they are being regularly published in proceedings of the Institute of World Resources (World Resources, 1992).

The most detailed and comprehensive estimations of Earth's water balance and water resources are presented in the two above capital monographs published more than 20 years ago by the

° Received December 4, 1998; revised April 27, 1999.

Biography: Professor I. A. Skiklomanov, Academician, Academy of Russia, Director, State Hydrologic Institute, St. Petersburg, Russia. vice-president, IAHS International Commission on Surface Water (ICSW).

Russian (World Water Balance…, 1974) and the German (Baumgartner and Reichel, 1975) scientists. So far these data are widely used by specialists of many countries as the most reliable. At the same time, as seen from comparison of the data cited in these monographs, they can differ of individual continents by up to 30%-40%. This difference is mainly attributed to the methods used for estimating the total river runoff. In Russian studies, they are determined directly from the data of observations at hydrological stations, in the German ones by indirect way—by the evaporation/precipitation difference. The latter approach, naturally, gives especially great errors with small values of river runoff. It is unusable for assessing water resources, and moreover their dynamics for countries and regions located in zones with insufficient moistening.

It should be mentioned that later publications citing some data on water resources of the continents, regions and countries of the world give no new information as compared with the above-mentioned studies. For instance, the values of water resources cited in the author's studies (Shiklomanov, 1990, 1993) are fully based on the materials of the monograph (World Water Balance…, 1974). The data, periodically published by the Institute for World Resources in Washington, D. C. (World Resources, 1992), represent a compilation from different sources. They refer to different years of assessment (from 1970 to 1987). They mainly belong to the Institute of Geography, the Russian Academy of Sciences (in practice, the data by Prof. Lvovitch M. I, 1969-1972), and some of the data are national estimates. This refers also largely to the study (Sustaining Water…, 1993), where citation is made of average values of renewable water resources for most of world countries. There are also specific indicators for per capita water availability in 1955, 1990, and 2025 with demographic forecast taken into account. In turn, publications of the Institute of World Resources are widely used by many authors to globally analyse water resources and water availability (Berner E. K. and Berner R. A., 1987; Falkner M. and Widstrand C., 1992; Kulshreshtha S. N., 1992; Postel S., 1992, etc.).

As to the global water use assessments, they have been made with different extent of comprehensiveness and reliability in many countries of the world. They are being regularly published beginning with the study by Doxiadis (1967). Of the most significant studies of this line, these by Lvovitch (1968, 1974), Holy (1974), Falkenmark and Lindth (1974), De Mare L. (1977), U. S. Geological Survey [The Global 2000…, 1980], and Ambroggi (1980) are worthy of notice. The most detailed assessments of world water use in dynamics for the current century with the forecast to 2000 by all continents were first made and published by the author jointly with G. P. Kalinin in 1974 (Kalinin and Shiklomanov, 1974). Specified and more detailed data by continents and natural-economic regions are presented by the author in the monograph (Shiklomanov and Markova, 1987). Later publications on water use by countries of the world (World Resources, 1992) give the data taken from different sources for different years. However there are no analysis and forecast of tendencies of their future changes.

Due to the existing situation with assessing world water resources and their use, the project

M . 3-1 to analyse new data on world water resources was included into the IHP-IV UNESCO. Fulfilling the project will result in publishing the monograph "World Water Resources at the Beginning of the 21th century." The Scientific Committee of the Russian Federation for IHP was responsible for fulfilling this project, and scientists of the State Hydrological Institute were charged with conducting the research and preparing the monograph.

By the present time this study is completed, and the manuscript of the monograph is prepared to be published in English by the Cambridge University Press by the end of this year. The monograph presents the new data on renewable water resources and water use dynamics (for 65 years) throughout the current century and for the future to 2010-2025 for the Earth, as a whole, all of the continents and natural-economic regions of the world, selected countries and river basins.

2 Initial Data and Methodological Features

To assess global water resources for the continents, regions, and countries located in different physiographic conditions, the observation materials from the world hydrological network have been used. Also the use was made of mateorological information, however as an auxiliary.

Observation data (monthly and annual values) from about 2500 hydrological sites, whose spread by continents is shown in Fig. 1, have been selected to directly assess renewable water resources at the global scale. The hydrological sites have been selected basing on the following conditions:

- the availability of the most long-term observation series;
- location of sites on big and medium rivers, uniformly spread over the teritory, if possible;
- observations should reflect river runoff regime, natural or close to natural.

The availability of long-term observation series was one of major conditions of selecting hydrological sites, as this corresponded to the basic accepted methodological principle: assessing water resources by all continents and regions of the world is to be carried out in dynamics for the single sufficiently durable long-term period.

The 1921-1985 period served as this single period. The data for later years were impossible to obtain for many regions of Africa, Asia, and South America. To obtain continuous data for the selected long-term period, the series were updated and the gaps in observations restored. For this purpose the use was made of the methodological approaches well known in hydrology: correlation models and hydrological analogy methods. In many cases to obtain more reliable results, meteorological data were used: observations of precipitation and air temperature. The acceptation of the single sufficiently durable design period allowed obtaining for all regions of the world average values of water resources comparable with each other and estimating rather reliably their extreme values and characteristics of long-term variability.

As a considerable part of land (to 15%-20%) is not covered with observation data, hydrological models and the methods for mapping runoff layer have been applied to calculate runoff from

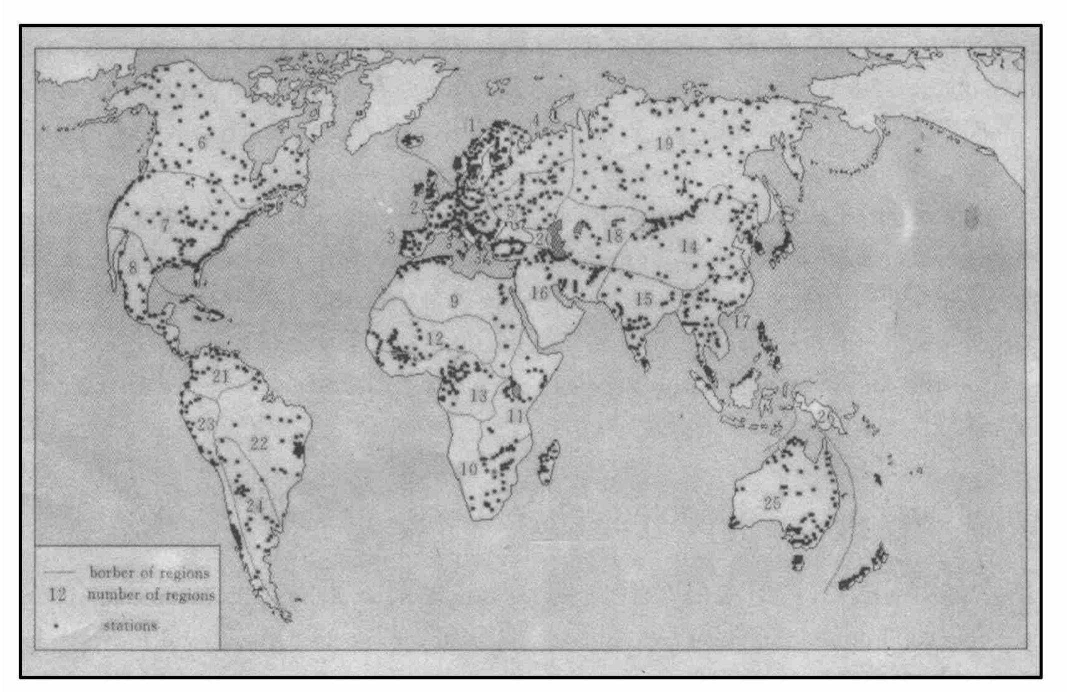

Fig. 1. The natural-economic regions of the world and gauge stations

图1 世界自然经济区和测站分布

these territories

To assess water resources of individual countries and natural-economic regions, if their borders do not coincide with river divides, specially developed hydrological methods were used to detemine by observation data major characteristics of renewable water resources of regions: local river runoff and river water inflow from adjacent territories.

In the present study, values of renewable water resources are identified with annual river runoff. For global assessments this is quite admissible, as renewable ground water resources not drained by rivers comprise a small proportion of the total river runoff (for instance for Africa, as a whole, about 5%). At the same time for individual countries located in arid regions these values can play a very great role in the total volume of renewable water resources.

The global withdrawal of water resources in the past and in the coming decades was assessed taking into account water use for public services, industrial production (including power engineering), agriculture (irrigation), as well as water loss by additional evaporation from reservoirs. These factors, causing one-sided decrease in surface and ground runoff, are widely spread, most intensively develop, and are able to exert an especially pronounced effect on water resources in large regions.

All assessments have been made for different design levels of the current century, the present time (1995), and the future (2000, 2010, and 2025).

The values of water use were estimated for individual countries and then generalised for large natural-economic regions of the world shown in Fig. 1, as well as for the continents. For this purpose national data on actual and calculated water use in individual countries or groups of countries were primarily used. With the absence of these data the proxy methods have been used. They were based on taking into account the major factors determining water use value and dynamics. In this case the wide use was made of the analogy method. The countries covered with reliable water use data, located in analogous physiographic conditions, and having similar level and features of economic development, were taken as analogues.

To forecast water use, the methodology was developed to take account of features and tendencies of water use for the previous decades as well as the available long-term demographic forecasts for countries and their economic development. The long-term UNIDO forecast (Strzepek et al., 1995) for industrial water use dynamics in countries to 2025 was also taken into account.

Specific water availability of regions and countries (in m^3 per capita) was analyzed for the period of 1950 to 2025 taking into account not only the population number but also the values of water consumption.

All the assessments for the future have been accomplished for a stationary climatic situation, as in accordance with recent studies the most considerable anthropogenic changes in global climate due to increasing CO_2 in the atmosphere are to be expected beyond 2030-2040

3 Renewable Water Resources: Time Variations and Spread Over the Territory

Renewable water resources determined by using the initial data and methodogical approaches for the continents of the Earth are presented in Table 1. By new data the total value of renewable water resources calculated for the period of 1921 to 1985 is estimated at 42 700 km^3/yr (without the Antarctic). It is approximately 4 800 km^3 above the values obtained by Baumgartner and Reichel (1975) and 1 800 km^3 below the previous detailed estimates of SHI (World Water Balance…, 1974). On the average, for 1994 potential population water supply was 7.6 thousand m^3/yr per capita varying by continents from 3.4 for Asia to 38 for South Americ, and 84 for Australia and Oceania. The value of water availability of Earth's population since the time of the previous estimation (for 25 years from 1970 to 1994) decreased by 1.7 times (from 12.9 to 7.6 thousand m^3/yr). This occurred basically due to population growth by almost 2 milliard people. Population water supply in Africa decreased most of all (by 2.8 times), Asia (by 2 times), and South America (by 1.7 times); whereas potential water availability of European population decreased as much as by 16%. It should be noted that actual water availability taking account of water consumption rise in addition to population growth decreased even more in countries of Africa, Asia, and South America.

Table 1. Renewable water resources and potential water availability by continents

表 1 各大洲可更新水资源量和潜在的可利用水量

Continent	Area, (mln·km²)	Population, (mln)	Water resources, (km³/yr) Average	Max	Min	Cv	Potential water availability, (1 000m³/yr) per 1 km²	per capita
Europe	10.46	1 685	2 900	3 210	2 440	0.10	277	4.24
North America	24.3	1 453	7 870	8 820	6 660	0.10	324	17.4
Africa	30.1	1 708	4 047	5 082	3 073	0.10	134	5.72
Asia	43.5	3 403	13 510	15 000	11 800	0.06	311	3.97
South America	17.9	1 315	12 030	14 350	10 330	0.07	672	38.3
Australia and Oceania	8.95	28.7	2 400	2 880	1 890	0.10	268	83.6
The world	135	5 590	42 757	44 460	39 660	0.02	317	7.65

Long-term variations in total river runoff of the continents and the Earth, as a whole, point to their cyclic character (Fig. 2). As seen from Fig. 2, there are cycles of wet and dry years changing each other and differing in duration and values of deviations from averages.

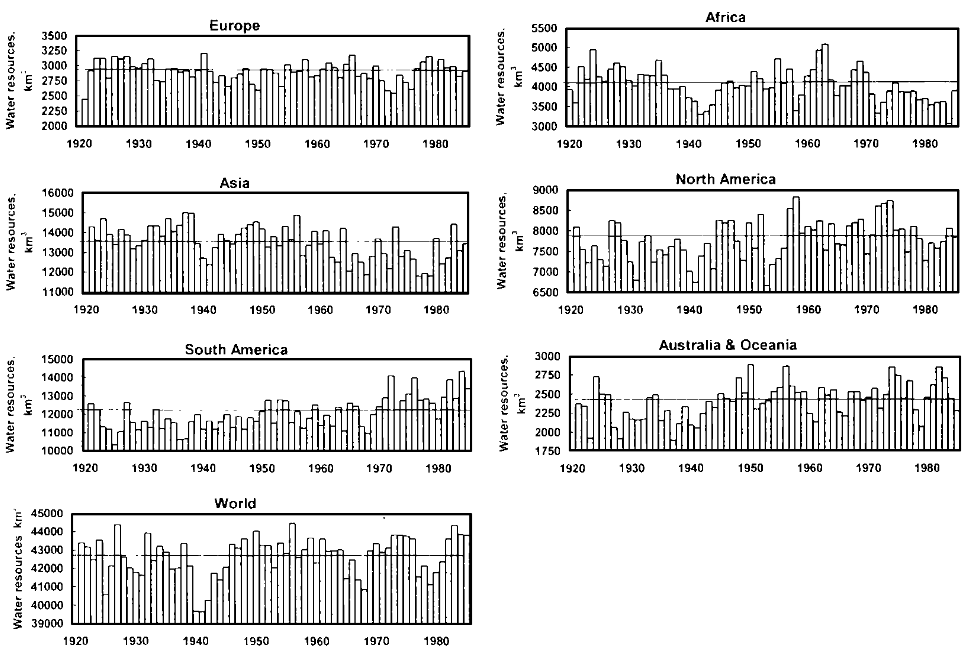

Fig. 2. Renewable water resources (km³/yr) of the world and the continents

图 2 世界和各大洲可更新的水资源

Along with the cyclic character of global river runoff variations, typical is the absence of any trend in changes for the entire 65-year period of study: rising river runoff of South America for the past two decades is compensated for by decreasing river runoff in Africa for the same period (Fig. 2). In most regions of the world, river runoff is irregularly spread during a year. Its greater part (60%-70%) is formed during the flood period. To a significant measure this refers also to the average data by continents, where for four flood months almost half the total annual river runoff passes. By modern estimates, in Europe, during April-July- 46% of annual runoff pass, Asia, during June-September- 54%, Africa, during September-December- 46%, North America, during May-August- 49%, South America, during April-June- 45%, Australia and Oceania, during January-April- 46%. As a whole for the entire land wet season lasts from May to August. For this season the total runoff of Earth's river comprises approximately 45% of the annual (Table 2).

Table 2. Streamflow distribution during a year by the continents (in % of the mean annual value)

表 2 各大洲河川径流的年内分配 (以占年均值的% 表示)

Continent	Mean annual water resources (local) km^3/yr	months												Year
		1	2	3	4	5	6	7	8	9	10	11	12	
Europe	2 900	6.2	6.6	6.9	8.9	14.3	13.3	9.2	7.6	7.3	6.9	6.6	6.2	100
North America	7 870	4.7	4.9	5.0	7.0	11.6	15.2	12.6	9.9	9.6	8.6	5.9	5.0	100
Africa	4 047	8.4	7.5	7.0	7.1	7.5	6.6	6.1	6.1	8.0	10.6	12.7	12.4	100
Asia	13 510	5.1	4.1	4.7	5.1	8.8	13.7	14.9	13.8	11.2	7.2	6.8	4.6	100
South America	12 030	5.9	7.0	8.1	10.0	11.4	12.1	11.1	9.7	7.6	6.0	5.5	5.6	100
Australia and Oceania	2 400	10.3	13.2	12.4	10.1	7.4	7.1	6.2	6.9	5.4	6.6	7.2	7.2	100
The world	42 757	5.9	6.1	6.5	7.6	10.2	12.5	11.7	10.4	9.0	7.4	6.8	5.9	100

The values of renewable water resources of natural economic regions averaged for 1921-1985 are presented in Table 3. There are also the data on long-term water resource variability (C_v) and potential specific water availability. The data on water resources are presented as local water resources (average, maximum and minimum) that are formed in the territory of the region, and an average inflow from adjacent territories. The numbers of regions in Table 3 correspond with numbers on the map (Fig. 1)

Table 3. Renewable water resources and potential water avaliability by natural-economic regions of the world

表 3 世界各自然经济区的可更新的水资源量和潜在的可利用水量

Number of region	Continent, region	Area (mln. km^2)	Population (in mln) 1994	Water resources				C_v	Potential water availability (in thou.m^3/yr)	
				Inflow (km^3/yr)	Local					
					average	min	max		per 1 km^2	per capita
	Europe	**10.46**	**684.7**		**2 900**	**2 440**	**3 210**	**0.10**	**277**	**4.24**
1	Northern	1.32	23.2		705	585	828	0.10	534	30.4
2	Central	1.86	293.0	6.0	617	353	836	0.21	332	2.12
3	Southern	1.79	188.0	109	546	377	838	0.18	305	3.19
4	North of the European part of FSU	2.71	28.5	27	589	434	775	0.12	217	21.1
5	South of the European part FSU	2.78	152.0	123	443	266	756	0.17	159	3.32
	North America	**24.3**	**453.0**		**7 870**	**6 660**	**8 820**	**0.10**	**324**	**17.4**
6	Canada and Alaska	13.67	29.0	130.0	4 980	4 360	5 830	0.10	364	174
7	USA	7.84	261.0	70.0	1 800	950	2 480	0.17	230	7.03
8	Central America and Caribbean	2.74	163.0	2.5	1 090	530	2 000	0.20	398	6.69
	Africa	**30.1**	**708.0**		**4 047**	**3 073**	**5 082**	**0.1**	**134**	**5.72**
9	Northern	8.78	157.0	140	41	19.0	96.0	0.34	4.67	0.71
10	Southern	5.11	83.5	86.0	399	270	549	0.14	78.1	5.29
11	Eastern	5.17	193.5	26.0	749	504	940	0.11	145	3.94

续表 3

Number of region	Continent, region	Area (mln·km²)	Population (in mln) 1994	Water resources				Cv	Potential water availability (in thou·m³/yr)	
				Inflow (km³/yr)	Local					
					average	min	max		per 1 km²	per capita
12	Western	6.96	211.3	30.0	1 088	581	1 948	0.28	156	5.22
	of which, Sahel	5.30	46.9	77.4	104	52.3	175	0.29	19.6	3.04
13	Central	4.08	62.8	80.0	1 770	1 453	2 263	0.09	434	28.8
	Asia	**43.5**	**3 403**		**13 510**	**11 800**	**15 000**	**0.06**	**311**	**3.97**
14	North China and Mongolia	8.29	409		1029	590	1735	0.23	124	2.52
15	Southern	4.49	1 207	300	1 988	1 535	2 458	0.10	443	1.77
16	Western	6.82	232		490	227	931	0.35	71.8	2.11
17	South East	6.95	1 442	120	6 646	5 342	7 607	0.09	956	4.65
18	Central Asia and Kazakhstan	3.99	54	46.0	181	121	265	0.17	45.4	3.78
19	Siberia and Far East of Russia	12.76	42	218	3 107	2 628	3 500	0.06	243	76.6
20	Transcaucasia	0.19	16	12.1	68	51.5	88.8	0.12	358	4.63
	South America	**17.9**	**314.5**		**12 030**	**10 330**	**14 350**	**0.07**	**672**	**38.3**
21	Northern	2.55	57.3		3 340	2 390	4 670	0.15	1310	58.3
22	Eastern	8.51	159.1	1 900	6 220	5 200	7 640	0.08	731	45.1
23	Western	2.33	48.6		1 720	992	2 380	0.18	738	35.4
24	Central	4.46	49.4	720	750	531	1310	0.17	168	22.5
	Australia and Oceania	8.95	28.7		2 400	1 890	2 880	0.10	268	83.6
25	Australia	7.68	17.9		352	228	701	0.24	45.8	19.7
26	Oceania	1.27	10.8		2 050	1 515	2 570	0.10	1614	190
	The world	**135**	**5 590**		**42 757**	**44 460**	**39 660**	**0.02**	**317**	**7.65**

The analysis of average values of water resources of the regions shows that they are mainly determined by climatic factors and inversely dependent on dryness index.

Year-to-year variability of water resources of regions can be rather significant and considerably exceed the averaged data by continents. Especially this pertains to arid and semiarid regions, where these values of water resources are not large. Here the variation coefficients (C_v) are 0.20～0.35 and in individual year the values of renewable water resources can be 1.5～2 times less than averages over a long-term period (Table 3). For wet regions the variation coefficients are 0.05～0.15, and the difference between annual and average long-term values of water resources is usually in the range of 15% to 25%. The dynamics of renewable water resources by regions of Africa is shown as an example at the Fig. 3. It can be seen that a trend of water resources decreasing is more remarkable for the Sahel zone and West Africa.

Many regions of the world show extremely uneven distribution of water resources during a year, when during the flood season lasting 3-4 months, 50%-70% of the annual runoff pass. At the same time for 3-4 months of low flow period in some regions, river runoff comprises as much as 2%-10% of the annual.

Of the greatest practical interest is a reliable assessment of renewable water resources of countries. This assessment has been made with different extent of comprehensiveness for more than 60 countries on all continents. Among the selected countries, there are developed and developing countries, countries with transitional economy, the largest in area and population and small, northern and southern, with deficit and excess of water resources. In the territory of

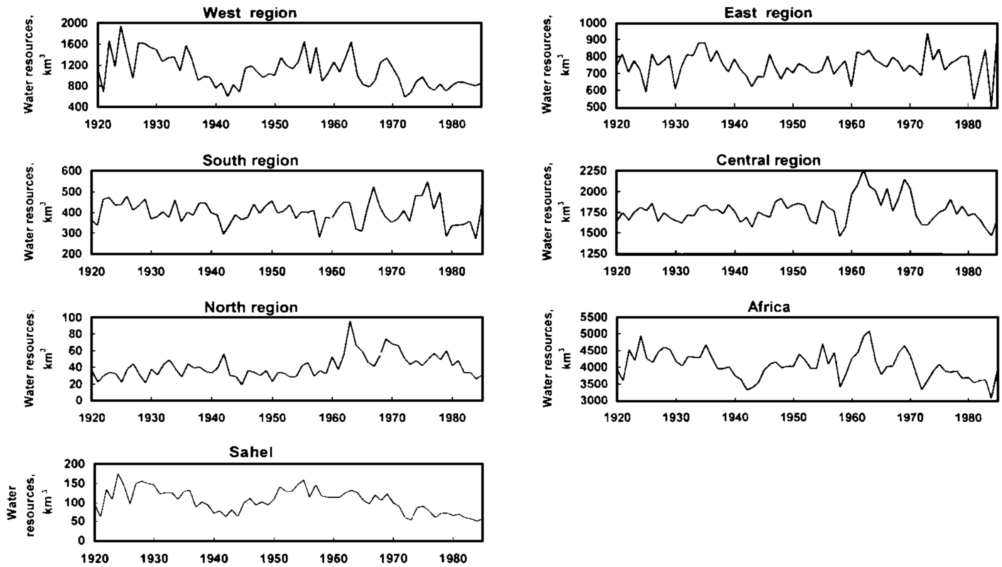

Fig. 3. Dynamics of renewable water resources (km³/yr) by the natural-economic regions of Africa

图3 非洲自然经济区可更新的水资源 (km³/a) 的动态变化

these countries, 70% of renwable water resources are formed, and about 70% of Earth's population live. The data obtained are testimony to an extremely uneven distribution of water resources and water availability by countries of the world. The values of specific water availability vary within a wide range: from 0.4- 5 thousand m^3 to 1 000- 1 800 thousand m^3 per year per 1 km^2, and from 0.18- 1.5 thousand m^3 to 100- 150 thousand m^3 per year per capita. Six principal countries of the world possess the greatest renewable water resources: Brazil, Russia, Canada, USA, China, and India. In the territory of these countries, more than 40% of the total annual river runoff of the world are formed. Year-to-year variability of water resources of Canada, USA, China, and India is characterised by the values of C_v= 0.10- 0.12, Brazil-C_v= 0.08, Russia-C_v= 0.05. For Brazil and Canada for the period under consideration, there are little tendencies toward increase, and for India and China toward decrease of renewable water resources.

4 River Water Inflow to the World Ocean

Generalising the world river runoff data makes it possible to estimate the dynamics of fresh water inflow to the world ocean, which is necessary to study its water balance and dynamic processes. It should be mentioned that river water inflow to the world ocean will be considerably less than the value of renewable water resources of the continents. This is caused by the two reasons. **First**, most of river basins enter the so-called endorheic, or drainless, runoff regions, not connected with the world ocean. **Second**, in the regions directly connected to the world ocean water resources of river basins can be considerably greater than runoff at river mouths. This is especially typical of some regions with hot climate, where water resources of the basins are formed in mountainous zones with great amounts of precipitation, and as moving to the mouth, a considerable portion of runoff is lost by evaporation in the plain and low land parts of the basin.

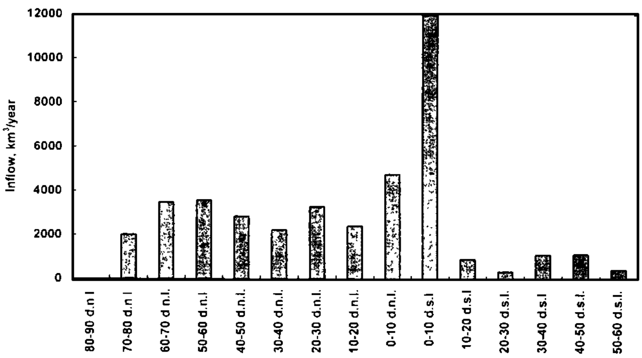

Fig. 4. River water inflow to the world ocean by latitudinal zones

图4 纬向带流入世界海洋的河川径流量 (km^3/yr)

Approximately half the total river water inflow to the world ocean falls on the Atlantic Ocean accepting four out of six principal rivers of the world (Amazon, Congo, Orinoko, Parana). The least amount of river water (4 300 km^3/yr) flows to the Arctic Ocean, however for its regime river water being of especially great importance. It can be explained in a simple way: in the Arctic Ocean, 1.2% of the total ocean water resources are concentrated, and about 11% of the world river water flow to it. The analysis of the data obtained shows that the total water inflow to the world ocean is quite stable and has no any distinct trend. At the same time during the period at issue, there is a noticeable tendency to decreased inflow to the Indian and Pacific Oceans and increased to the Atlantic Ocean.

River runoff inflow to the world ocean is extremely uneven by territory. This is seen from the data presented in Fig. 4, where the demonstration is made of the distribution of inflow to the world Ocean by latitudinal zones. In the equatorial belt between 10^0N and 10^0S, about 40% of the total river runoff, on the average, flow into the ocean.

5 Dynamics of Fresh Water Use

Figure 5 depicts water use dynamics by continents and for the world, as a whole, through the present century and to 2025. the modern (for 1995) water withdrawal in the world is 3 750 km^3/yr, consumption- 2 280 km^3/yr. In the future water withdrawal will grow by about 10% - 12% for each period of 10 years and reach 5200 km^3/yr to 2025 (a 1.38-fold increase). At the present time about 5% of global water withdrawal and 70% of consumption fall on Asia, where principal irrigated lands of the world are located. The most intensive growth of water withdrawal for the next decades is expected to occur in Africa and South America (by 1.5-1.6 times), the least in Europe and North America (by 1.2 times).

At the present time, 67% of water withdrawal and 86% of consumption fall on agriculture (Fig. 5). In the future the role of agriculture will slightly decrease due to an expected more intensive growth of other water users, primarily, industry and public services. By specified data the total irrigation area in the world in 1995 was 254 million ha; by 2010 it is expected to increase approximately to 290 million ha and by 2025 to 330 million ha.

The above prediction estimates refer to moderate climatic conditions (without taking into account possible anthropogenic changes in global climate) and to the most realistic scenario of developing world economy. Taking account of uncertainties in developing economy, population growth and climatic situation, by 2025 the total water withdrawal is expected to be within the range of 10% - 12% of the above average value, i. e., 4 600 - 5 800 km^3/yr.

In 1996 due to preparing a report on assessing the condition and prospects of fresh water use in the world for the UNO Commission on Sustainable Development, the forecasts were made of world water use by 2025 by the International Group of Experts under the Stockholm Institute for the Natural Environment (SEI). These forecasts were based on the future scenario of conventional development ("Conventional Development Scenario") created by SEI Boston. Simultaneously in 1996 the water use forecast for 2025 was developed by FAO. This forecast proceeded from demands for fresh water to provide the growing Earth's population with food. The values of the SEI and FAO forecasts for 2025 are presented in Fig. 5. These latest, apparently most substantiated from different positions, forecasts of global water use considerably differ from each other (on the average, from 4 500 to 7 000 km^3/yr by 2025). The SHI prediction estimates obtained earlier (1995) independently are between the extreme values of the SEI and FAO forecasts, which points to their sufficient reliability.

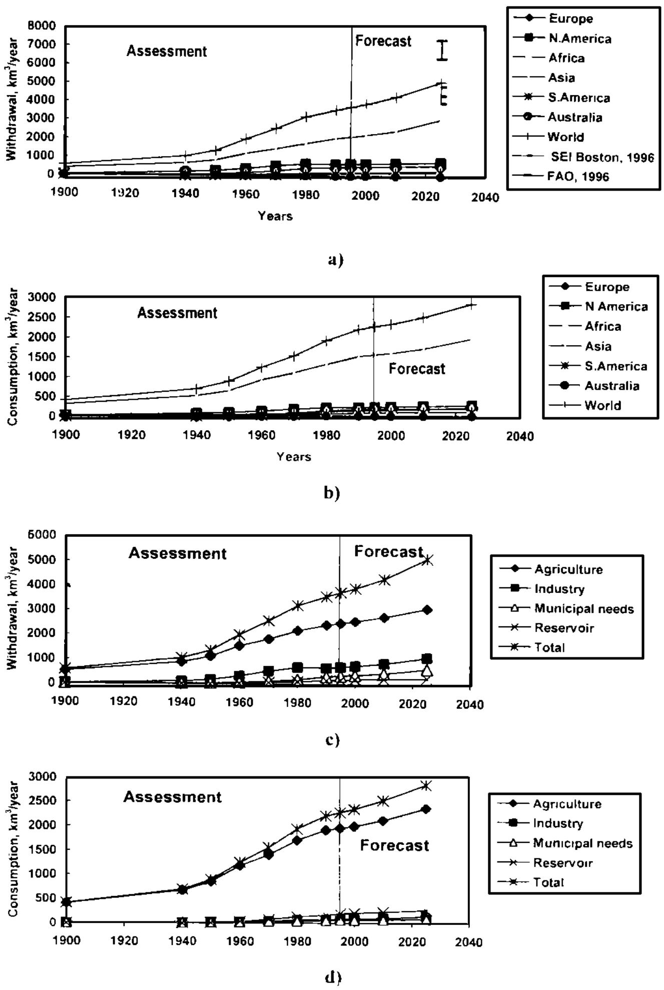

Fig. 5. Dynamics of water withdrawal (a) and water consumption (b) in the world by the continents & dynamics of total water withdrawal (c) and water consumption (d) in the world over the kinds of economic activities

图 5　世界各大洲的取水量 (a) 和耗水量 (b) 的动态变化及世界各种经济活动的取水量 (c) 和耗水量 (d) 的动态变化

Water use dynamics was obtained for all natural-economic regions of the world; the main results of the values of the total water use during 1900-1995 and for the future before 2025 are shown at the Table 4. The intensity of water use growth from 1995 to 2025 is different by regions. In developed countries and in these with limited water resources, water use is expected to increase by 15% - 35%, in regions with developing countries with sufficient water resources-by 100% - 200%.

The analysis of water use values obtained shows that they are determined to a large extent by not only social-economic conditions but also by climatic factors.

Table 4. Dynamics of water withdrawal by continents and natural-economic regions of the world in km^3/yr

表4 世界各大洲和自然经济区的取水动态变化 (km^3/yr)

Number of region	Continent, region	Assessment								Forecast		
		1900	1940	1950	1960	1970	1980	1990	1995	2000	2010	2025
	Europe	**37.5**	**71.0**	**93.8**	**185**	**294**	**445**	**491**	**511**	**534**	**578**	**619**
1	Northern	1.4	2.8	3.9	7.5	9.8	11	11.4	12.3	13.2	14.8	16.4
2	Western and Central	12.8	21.5	31.5	87.2	120	142	150	161	173	192	208
3	Southern	16	27.1	37.4	53.9	88.6	155	174	184	194	208	212
4	North of the European part of FSU	0.3	0.8	0.9	1.8	3.1	13.9	16.3	15.4	14.9	16.8	20.3
5	South of the European part of FSU	6.9	18.8	20.2	34.4	72	123	139	139	139	146	162
	North America	**70**	**221**	**286**	**410**	**555**	**677**	**652**	**685**	**705**	**744**	**786**
6	Northern	2.6	8.8	13.2	19.2	26.1	41.4	52.4	56.1	58.4	64.9	73.7
7	Central	54.2	191	247	347	470	538	492	503	512	530	550
8	Southern	12.8	20.9	25.6	44.2	59.4	97.5	108	127	135	149	162
	Africa	**41.0**	**49.3**	**56.0**	**85.9**	**116**	**168**	**200**	**215**	**230**	**270**	**331**
9	Northern	37	41	43	65	78	100	106	110	114	127	144
10	Southern	1.9	4.4	6.5	10	16	23	24.5	26.4	28	33	43
11	East	1	2.1	3.7	6.1	12	23	44.7	50.4	56	68	83
12	West	1	1.5	2.3	3.8	8.4	19	22.7	26.0	29	37	52
	of which, Sahel							5.71	6.49	7.27	9.63	13.8
13	Central	0.1	0.3	0.5	1	1.6	2.8	2	2.5	3	4.5	9
	Asia	**414**	**689**	**860**	**1222**	**1499**	**1784**	**2067**	**2157**	**2245**	**2483**	**3104**
14	North China and Mongoloa	37	67	98	165	217	241	234	254	273	305	373
15	Southern	201	312	367	429	524	668	895	932	969	1060	1370
16	Western	43	69	91	136	158	192	227	238	248	283	346
	of which, Arab Peninsula							21.9	26.1	30.4	36.2	44.9
17	South East	99	170	230	399	469	484	499	525	551	617	781
18	Central Asia and Kazakhstan	29	55	57	67	94	151	156	154	151	160	169
19	Siberia and Far East of Russia	0.7	4.9	5.6	10.4	16.3	25.4	31.3	30.6	30	32	38
20	Transcaucasia	4.2	11.3	11.4	15.8	20.7	23	24.4	23.7	23	26	27
	South America	**15.2**	**27.7**	**59.4**	**68.5**	**85.2**	**111**	**152**	**166**	**180**	**213**	**257**
21	Northern	1.6	4.2	6.4	7.7	11.3	15.4	22.1	24.5	27	32	41
22	Eastern	1.1	2.1	3	7.3	12.1	23.2	43	49.0	55	69	88
23	Western	8.9	14.9	36.7	37.5	35.8	40	45	47.1	49	55	64
24	Central	3.6	6.5	13.3	16	26	32.6	42	45.6	49	57	64
	Australia and Oceania	**1.6**	**6.8**	**10.3**	**17.4**	**23.3**	**29.4**	**28.5**	**30.5**	**32.6**	**35.6**	**39.6**
25	Australia	1.5	6.2	9.4	16	21.4	27	25.5	27.1	28.9	31.7	35.2
26	Oceania	0.1	0.6	0.9	1.4	1.9	2.4	3	3.4	3.7	3.9	4.4

6 Renewable Water Resources and Water Use

The extent of using fresh water is found by the coefficient K_w equal to the ratio between water withdrawal and renewable water resources. The K_w values have been obtained for all natural-economic regions and selected countries of the world. In the present study all regions and countries by the level of using water resources are united into four categories:

Category 1: K_w = 10% - a low load on water resources;

Category 2: K_w = 10-20% - a moderate load;

Category 3: K_w = 20-40% - a high load;

Category 4: K_w = > 40% - a very high load on water resources.

Basing on the above classification it might be concluded that in 1950 in the world, there was quite a favourable situation with water resources. There was no region with a very high load on water resources. Category 3 (load of 20-40%) included only two regions (North Africa and Central Asia, and Kazakhstan), in the rest regions of the world, there was a low or moderate load on water resources.

By the present time the pattern has cardinally changed. In many regions of the world, there is a high or very high load on water resources; in these regions, there are more than 70% of Earth's population. By 2025 the situation will deteriorate even more, especially in developing countries of all continents. By that time Earth's population by 80% is expected to live in the conditions of high and very high load on water resources. The third part of Earth's population will produce a load on water resources with K_w > 60%, which can be classified as a catastrophically high.

7 Tendencies to Changing Water Availability: Water Resources Deficit

The analysis of specific water availability values for all regions and selected countries of the world between 1950 and 2025 shows their extremely great unevenness of spread over the planet's territory. For 1995 the greatest water availability of 170- 180 thousand m^3/yr per capita was recorded in regions of Canada with Alaska and Oceania. At the same time in densely populated regions of Asia, Central and South Europe, and Africa, water availability is in the range of 1.2 to 5.0 thousand m^3/yr. In northern Africa and on the Arab Peninsula, it is as much as 0.2- 0.3 thousand m^3/yr. Let us note that water availability of less than 2 thousand m^3/yr per capita is assumed to be very low, and below 1 thousand m^3- catastrophically low. With these values of water availability very serious problems with population life-support, developing industry and agriculture are unavoidable. At present totally 76% of the world population live in the conditions of specific water supply of below 5.0 thousand m^3/yr per capita, and 35% have a very low or catastrophically low water supply.

The situation will be much worse in the beginning of the next century. By 2025 a greater part of Earth's population is expected to live in the conditions of a very low and catastrophically low water availability or close to this, and about 30%～35% of the world population will have a catastrophically low water supply.

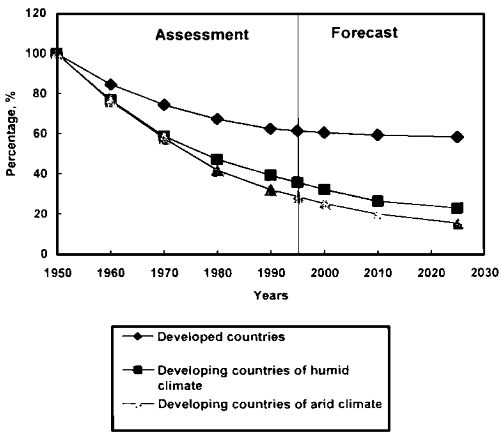

Fig. 6. Dynamics of specific water availability by natural-economic regions of the world in percentage 1950- 2025

图6 1950- 2025年世界自然经济区的特定可利用水量的动态变化(%)

Important inferences have been drawn in analysing the tendencies and rates of changing specific water availability of countries and regions depending on social-economic and physiographic conditions (Fig. 6). For industrially developed countries the level of specific water availability reduction is comparatively low, and independent of climatic conditions and water resources values it comprises on the average 1.8 times for 1950- 2025. For developing countries the rates of decreasing specific water availability are being drastically increased amounting to 4.5 times, on the average, for sufficient and excessive moistening conditions. For insufficient moistening and arid conditions they are being increased by 8.5 times, on the average.

Thus a very great natural unevenness in water availability spread that takes place on the Earth will be ever increasing with time by quite fast rates due to economic activities and population growth.

In conclusion it should be noted again that all the above assessments for the future are based on the stable climatic situation, it means that they do not take into account the possible anthropogenic global climate change caused by the increasing of greenhouse gases in the atmosphere. The consideration of the global warming processes can be especially important for the water availability assessment in the regions of the insufficiently moistening, where the hydrological characteristics are very sensible (Shiklomanov I A. & Lins H. 1991) to the insignificant climate changes.

References:

[1] Ambroggi R P. Water. Scientific American. 1980, 243(5): 90～96, 100～101.

[2] Biswas A K. Water resources in the 21st century. Water international, 1991, 16(3): 142～144.

[3] Baumgartner A, Reichel E. The World Water Balance. R. Oldenboury Verlag Munchen. Wien, 1975, 180.

[4] Berner E K, Berner R A. The Global Water Cycle: Biochemistry and Environment, reprinted, adapted by permission of Prentico Hall. Englewood Cliffs, New Jersey, 1987. 13～14.

[5] DeMare L. An assessment of the world water situation by 2000. Water. Int. IWRA. 1977, 2(9).

[6] Doxiadis C A. Water for human environment: proc. of the con. "Water for Peace", v. 1,

Washington 1967. 33～60.

[7] Falkenmark M, Lindth G. How can we cope with the water resources situation by the year 2015? Amino. 1974, 3(3): 114～121.

[8] Falkenmark M, Widstrand C. Population and Water Resources: A Delicate Balance. Population Bull. Population Reference Bureau.

[9] Holy M. Water and the Environment. Roma. FAOU. N. 1971.

[10] Kalinin G P, Shiklomanov IA. Water resources development. In: "World Water Balance and Water Resources of the Earth". Leningrad, Hydrometeoizdat, 1974: 575～604 (in Russian).

[11] Kulshreshtha A N. World Water Resources and Regional Vulnerability: Impact of future changes. IIASA Luxembourg, Austria, 1992, 138.

[12] Lvovitch M I. Water resources of the future. Moscow, "Prosveshcheniye", 1969, 175 (in Russian).

[13] Lvovitch M I. World water resources in their future. Moscow, "Mysl", 1974, 263 (in Russia).

[14] Nace R. Are we running out of water? US Geological Survey Circular. 1967, N. 536, Washington D. C.

[15] Postel S. Last Oasis. The World-watch Environment Alert Series, 1992, 239.

[16] Shiklomanov IA. Global Water Resources. Nature and Resources 1990, 26(3): 34～43.

[17] Shiklomanov IA, Lins H. Climate variation effect on hydrology and water management. J. Meteorolog and Hydrology, 1991, 4: 51～65.

[18] Shiklomanov IA. World fresh water resources. In monograph "Water in Crisis". Oxford University Press, 1993, 13～25.

[19] Shiklomanov IA, Markova O L. Problems of water availability and water transfers in the world. Leningrad, Hydrometeoizdat 1987, 293 (in Russian).

[20] Strzepec K, Bowling P. UNIDO Global Industrial Water Use Assessment. Draft, 1995, 29.

[21] Sustaining water. Population and the Future of Renewable Water Supplies. Population Action International 1993, 56.

[22] The Global 2000. Report to the President of the US. Entering the twenty first century. Washington D. C. US Government Printing Office. 1980, 1～3.

[23] World Resources. 1992～1993, 1992. A Guide to the Global Environment. Oxford University Press, P. 385.

[24] World Water Balance and Water Resources of the Earth. Hydrometeoizdat. L.: 1974, 638 (in Russian).

世界水资源和用水：当代评价和未来展望°

I A. 谢克洛莫罗夫

(俄罗斯国立水文研究所，圣彼得堡)

摘要：1990～1996，俄罗斯国立水文研究所的科学家，在本文作者的科学指导下，对世界水资源、用水和可用水量的动态变化作了新的综合评价，也对其未来状况进行了预测。

依据世界水文站网资料，简明地给出了世界各洲、不同自然地理和经济区，以及一些选定国家的可更新水资源动态数据；给出了满足人口、工农业需要的全球用水量，以及本世纪和未来(2000、2010 和 2025 年)的动态可利用水量；分析了世界水资源、用水和可利用水量变化的长期趋势，后者与气候因素和社会经济因素的有关。

本项研究成果将以专著《21 世纪初期世界水资源》于 1999 年由剑桥大学出版社出版。

关 键 词：世界水资源；用水；可用水量；评价；展望

中图分类号：TV 21 **文献标识码**：A

° **收稿日期**：1998-12-04；**修订日期**：1999-04-27

作者简介：I A. Shiklomanov，现任俄罗斯国立水文研究所所长、俄罗斯科学院院士。90 年代以前从事水文学研究，90 年代以来主要从事水资源研究，著有《World Water Balance and Water Resources》等专著。