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Water Balance Model for Vulnerability Assessment of Water Resources in Strumica River Basin

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Abstract

Water resources are the most important part of the ecosystems in the Republic of Macedonia and are sensitive to climate change with regard to both, quantity and quality. Also, they are the most spatially diverse and are closest to the area of human activities. Due to the geographical location a major portion (84%) of surface water is domestic.

This paper presents the vulnerability assessment of the water resources on climate change for Strumica river basin in south eastern part of the Republic of Macedonia conducted within the Third National Communication. Statistical trend analyses have been obtained on basic parameters such as air temperature, precipitation, and runoff with special attention to the southeast part of the country that was assessed within the First and Second National Communication as the most vulnerable region in the country. It was concluded that maximum runoff has no significant changes in either short-term or long-term trends. Statistical trends of the recorded precipitation and surface runoff indicate that the last decade can be recognized as a hydrological wet period. An approximate water balance model was conducted presenting the current condition (2000/2010) and projected condition (2025).

In summary, as in other countries, the water resources in the Republic of Macedonia are vulnerable to potential changes in climate because of increasing demands, the sensitivity of simple water management systems to fluctuations in precipitation and runoff, and the considerable time and expenses required to implement adaptation measures.

Keywords: Water resources; Climate change; Vulnerability assessment; Water balance

Strumica River Basin Watershed

Hydrographical characteristics

The Strumica river basin is 1.649 km^2 that is 6,4% of the territory of the Republic of Macedonia. The major part of the total watershed (75%) is in Macedonia, while the remaining is in Bulgaria and Greece. River Strumica takes its source from the Plackovica Mountain at an altitude of 1.540 m asl running south in a deep valley and known as the Stara Reka [1-3]. It then enters the Radovish valley and runs through the eponymous Radovis. Afterwards the river runs southeast trough the Strumica valley passing through the town of Strumica and turning east to enter Bulgaria south of Zaltarevo. The main tributaries are Turija, Vodocnica, Radoviska and Podareshka. From both sides of the Strumica River there are a large number of tributaries mostly mountainous streams with permanent water flow. River outflow Macedonian border southeast of Novo Selo and inflow Struma River in Bulgaria at an altitude of 186 m asl. It is the Struma's largest tributary. Total length of Strumica River is 114 km out of which 81 km in Macedonia and 33 km in Bulgaria [4].

The area of Strumica river basin although is hydrographically well developed is the poorest in water resources and the lack of water affects all segments of human activities: water supply especially in rural areas, industry and irrigation. This also aggravates the water quality and flow rates are often less the biological minimum in the periods when the streams dry up. The annual average of total available water is approximately 132 million m^3 with specific runoff of 3,1 l/s·km^2.

The annual average discharges of Strumica River for the period 1961-2010 at the gauging station Suševo is 1,61 m^3/s, and for the last decade 2001-2010 it is 2 m^3/s. The maximum floods have been recorded in 1962 (210 m^3/s) and in 2010 (155 m^3/s). Data on recent floods in February 2013 are not available yet by the authorized Hydrometeorological agency (HMA). The average discharges at the gauging station Novo Selo for the period 1961-2008 is 3,86 m^3/s and for the last decade 2001-2008 it is 4 m^3/s. The maximum flood 280 m^3/s is recorded in 2004.

This river basin is assessed as poorest in water resources. To meet the water demands for drinking, industry and irrigation, dams with reservoirs are constructed. The largest reservoir is Turija constructed in 1970 and situated 10 km north from Strumica on Ogražden Mountain. The lake water surface is 1,8 km^2 and the reservoir storage capacity is 50 million m^3. Main purpose of the reservoir is irrigation, water supply and hydropower [5].

Second size reservoir is Vodoča constructed in 1965 and situated approximately 6 km south from Strumica. It covers a water surface area of 1,94 km^2 with storage capacity of 26 million m^3. The water is used for irrigation and water supply.

Smaller reservoirs are: Novoselka near the village of Novo Selo with storage capacity of 500.000 m^3 and with primary water use for irrigation and water supply, Čaušica with storage capacity of 100.000 m^3 which water is used only for irrigation, Ilovica with storage capacity of 500.000 m^3 and water use in irrigation and water supply for municipality of Bosilovo, Konče 1 and Konče 2 with water use in irrigation and water supply of the village Konče.

The reservoir near the village of Mokrievo with storage of 26.000 m^3 is used for water supply of nearby villages. The main problem in the

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watershed of Strumica River is a water shortage. There is a water transfer from the reservoir Mantovo on Lakavica river basin to Strumica river basin. There is no data how much water is transferred on annual basis.

On the north of Belasitza Mountain there are a number of springs and about 10 villages have constructed their own water supply systems. Most of the springs are registered in subwatershed of Strumica and Radoviš, (Table 1). The waterfalls Mokrinski, Smolarski and Kolesinski are very important water resources for the tourism development in the región [6].

Municipalities and population

The Republic of Macedonia is organized into 84 municipalities, Figure 1. Within the Strumica river basin there are six municipalities which area and population is presented in Table 2. According to the State Statistical Office of the Republic of Macedonia the Natural Growth rate for south-eastern part of the country is 0.06% based on data from census in 2004.

Groundwater

Strumica watershed is characterized with aquifers mainly on northwest to southeast direction with different permeability. There is a compact formation of Quaternary-Pliocene sediments with free water level along rivers Stara Reka, Strumica, Turija, Štuka and others. In the of Quaternary-Pliocene sediments in the central part of Strumica valley (villages Sofilari, Murtino, Dabile, Bosilovo) compact type with water level under pressure is present. Karst-fissure formation is located at the fringe of Radoviška-Strumicka depression. High water permeability is Q=10-50 l/s (T=300-1.500 m/day) and low water permeability is Q=0,5-2 l/s (T=15-20 m/day). Groundwater is used for water supply, irrigation and industry. Geothermal water is also present in Bansko-Strumica.

The report on integrated management of transboundary aquifers in sotheastearn Europe (INWEB, 2007) describes most aquifers as karst aquifers where water moves very quickly trogh large conduits and hence receives little infiltration. This report mentions two transboundary aquifers that lie nearby the Strumica river basin: the Dojran Lake Aquifer and the Sandanski-Petrich Aquifer. Both aquifers are alluvial which exact location and characteristics are not given. The water flow in these aquifers is very slow and when the alluvial aquifers become contaminated, remediation is very difficult [7].

Geological eras in Strumica river basin are Cenozoic in central part along the main stream, Paleozoic and Precambrian in mountainous parts on both sides of the main stream and small part on south belongs to Mesozoic, (Figure 2).

Groundwater monitoring in Strumica river basin was performed within 23 piesometric wells established in 1953 (villages Sofilari, Murtino, Dabile, Bosilovo, Monospitovo, Novo Selo, Radovish and others). Unfortunately, since 2000 only two of them are operating, Bosilovo and Monospitovo. Organozed groundwater data collection and management is missing, as well as the user cadastre. The estimated static reserves mainly in the aquifers of consolidated type with water level under pressure (artesian) are 850 million m^3.

Subbasin/ Valley	Number	Average	Total	Free flowing	Tapped/ Captured
Radoviš	80	0.008	0.61	0.47	0.14
Strumica	145	0.039	5.59	4.16	1.43

Table 1: Springs' yield in Strumica river basin in (MCM/year).

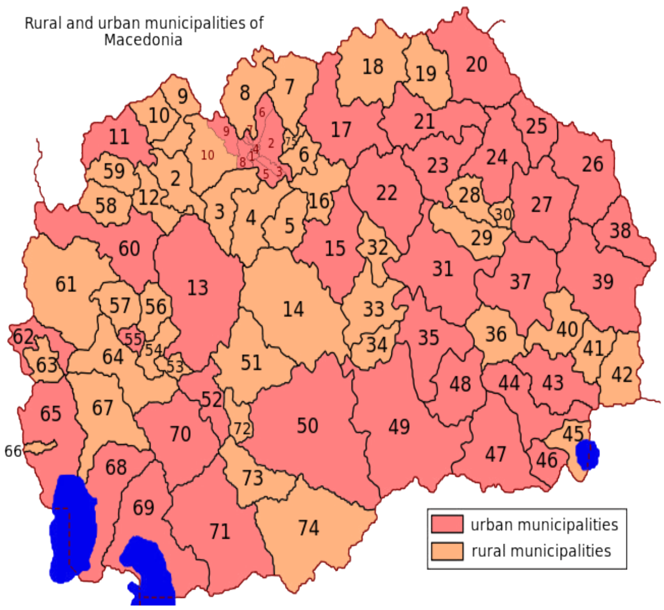

Figure 1: Map of rural and urban municipalities in Macedonia.

No	Municipality	Area (km^2)	Population (2004)
41	Bosilovo	143	14.260
36	Konče	233	3.536
37	Radoviš	502	28.244
40	Vasilevo	t231	12.122
43	Strumica	311	54.676
42	Novo Selo	257	11.567

Table 2: Municipalities in Strumica river basin.

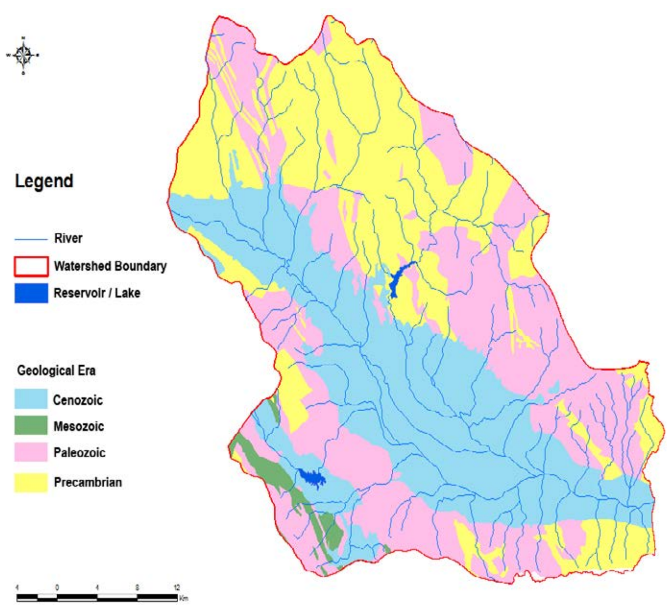

Figure 2: Geological eras of Strumica river basin.

Monitoring

Monitoring network in Strumica river basin related to water is structures by meteorological stations, hydrological stations and rain

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gauges. Main meteorological station is established in Strumica (223 m asl), climatological station in Radoviš (380 m asl). Hydrological stations are placed at Smiljanci in the upper part, at Sushevo in central part and in Novo Selo in lower part of the watershed, (Figure 3). Groundwater is also monitor at villages Sofilari, Murtino, Dabile, Bosilovo, Monospitovo, Novo Selo, Radovish and others, but unfortunately since 2000 only two of them, Bosilovo and Monospitovo, are in operation.

Rain gauges are established in Podaresh (320 m asl), Veljusa (400 m asl), Gradoshorci (240 m asl), Dobrashinci (280 m asl), Kalugjerica (390 m asl), Kozbunar (1.130 m asl), Kosturino (435 m asl), Monospitovo (207 m asl), Rich (580 m asl), Smolari (380 m asl), Hamzali (290 m asl) and Novo Selo (290 m asl). Short-lasting rainfalls with destructive flood effects are becoming more frequent in Strumica watershed. In Figure 4 is presented map of the annual rainfall distribution in Strumica watershed based on which the average annual precipitation 688 mm is obtained. Only the mountainous regions on northeast and south of the watershed have greater precipitation sums over 1.000 mm and the central part in Strumica valley is rather poor with precipitation less than 500 mm annually.

The air temperature distribution within the watershed is presented in Figure 5. The average annual air temperature of the entire watershed is 8°C that is less than the long-term average annual temperature 12.9°C obtained for Strumica meteorological station [8].

Problems on monitoring issue are related mainly to lack of data and/or not availability of data. Some of rain gauges and water gauges do not operate any more due to financial problems, and some do not have systematic measurements and the existing time series data are with significant gaps. For the Third National Communication on CC monthly data on air temperature and precipitation for the period 1951-2010 have be collected from Strumica meteorological station. Runoff data for the period 1961-2010 have been collected for two hydrological stations-Sushevo and Novo Selo.

Land use

The main land use type in Strumica River watershed is agriculture.

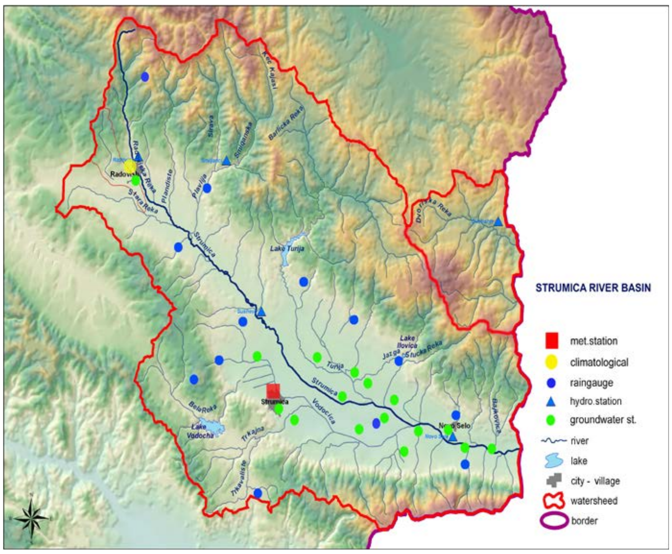

Figure 3: Strumica river basin monitoring network.

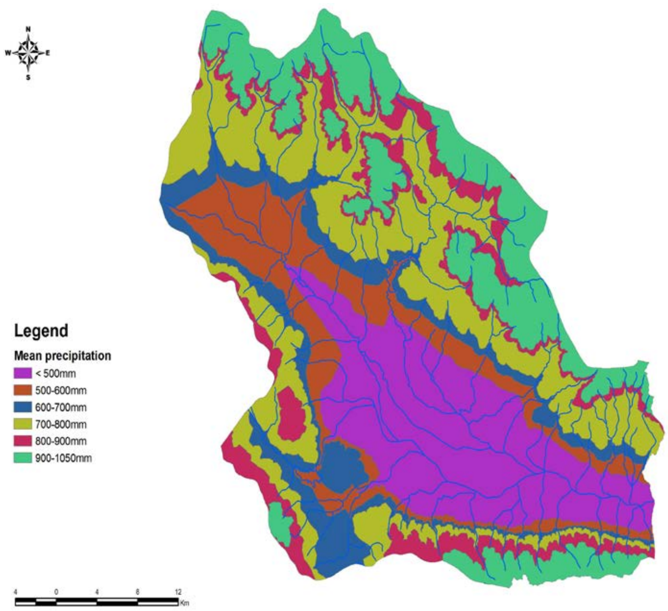

Figure 4: Mean precipitation distribution in Strumica river basin.

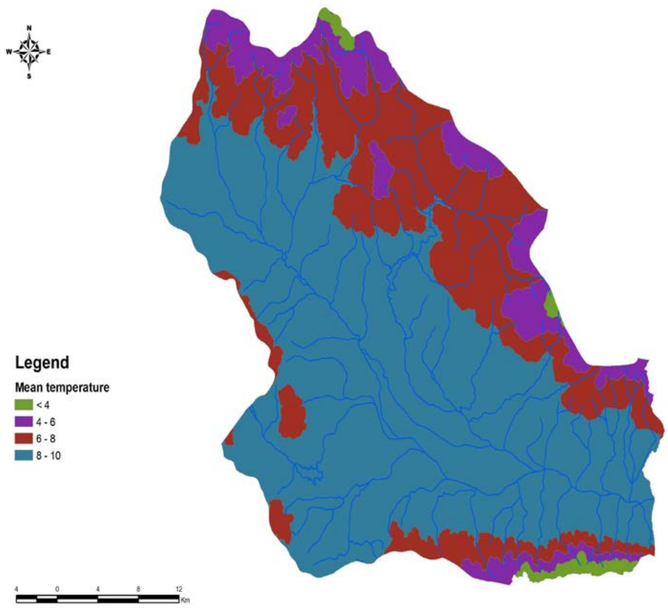

Figure 5: Mean air temperature distribution in Strumica river basin.

Large parts of this arable land are irrigated. Land covered with artificial surfaces, cities and industry, participate only a very small part. The slopes of mountains Ograzden, Belasica, Elenica, Pljackovica and Plavus are characterized by rich forests. The land use and land cover data are obtained by CORINE Land Cover (CLC) EU database/map which provides comparable digital maps on land cover, biotopes, soil, and acid rain for over 22 countries in Europe. The map was created in GIS ARC/INFO format based on the interpretation of satellite images with land cover types in 44 standard classes. Land cover/use map for Strumica watershed is presented in Figure 6 and types of land cover/use are shown in Table 3. The broad-leaved forests cover about 60.000 ha, mixed forests cover about 2.300 ha, and pastures participate with

128.000 ha, while the non-irrigated arable land covers about 197.000 ha. By their structure the forests are oak, beech, chestnut, walnut, black and white pine trees and others. The quality forests are between 1.000 and 1.500 m above sea level, while those up to 500 m are mainly degraded or brushes. By water bodies is covered only 1.200 ha [9].

Erosion

In the Republic of Macedonia torrential flows are very often. According to the Erosion map of RM territory is divided in 5 classes of erosion intensity – from class I representing extreme erosion to class V representing very low erosion. The erosion intensity in Strumica watershed is estimated as low (class IV) with erosion coefficient 0,2-0,4. The areas of particular category of erosion intensity are 1.139 km^2 in category IV-V and 381 km^2 in category I-III. Constructed small reservoirs in the watershed have significant sedimentation. The annual sediment yield in Vodoca and Turija reservoirs is estimated to be 37.327 m^3 and 91.578 m^3 with annual erosion rate 0,49 mm and 0,43 mm respectively, JICA (1999).

Water quality

Surface water quality monitoring is performed by Hydro-Meteorological Administration (HMA) in Skopje (rivers, reservoirs and groundwater) and Hydro-Biological Institute (HBI) in Ohrid (natural lakes). Based on the Law on waters (Official Gazette of RM, No. 4/98), the Government of the Republic of Macedonia brought a "Regulation for Classification of Water" (Official Gazette of the Republic of Macedonia No. 18/99). Surface waters, rivers, natural and man-made lakes and groundwater are classified within five clases [10]. This Regulation doesn't apply to mineral and thermal waters. Short description of the quality classification is as follows:

Class I: Very clean, oligotrophic water, which in its natural state, with possible disinfecting, can be used for drinking, production and processing of food product and is suitable for mating and cultivation of noble types of fish (salmonides). The buffering capacity of the water is very good.

Class II: Very clean, mesotrophic water, which in its natural state can be used for bathing and recreation, water sports, production of other types of fish (cyprinid species), or which can be used , after usual methods of purification (coagulation, filtration, disinfections etc.), for drinking, production and processing of food products. The buffering capacity and oxygen saturation throughout the whole year is good. The loadings may lead to slightly increased primary productivity.

Class III: Moderately eutrophic water, which in its natural state can be used for irrigation, and after usual purification methods (conditioning) for industries, which do not need drinking water quality. Buffering capacity of the water is low, but it maintains the (pH value) acidity at a level still suitable for most fish. In hypolimnion occasionally

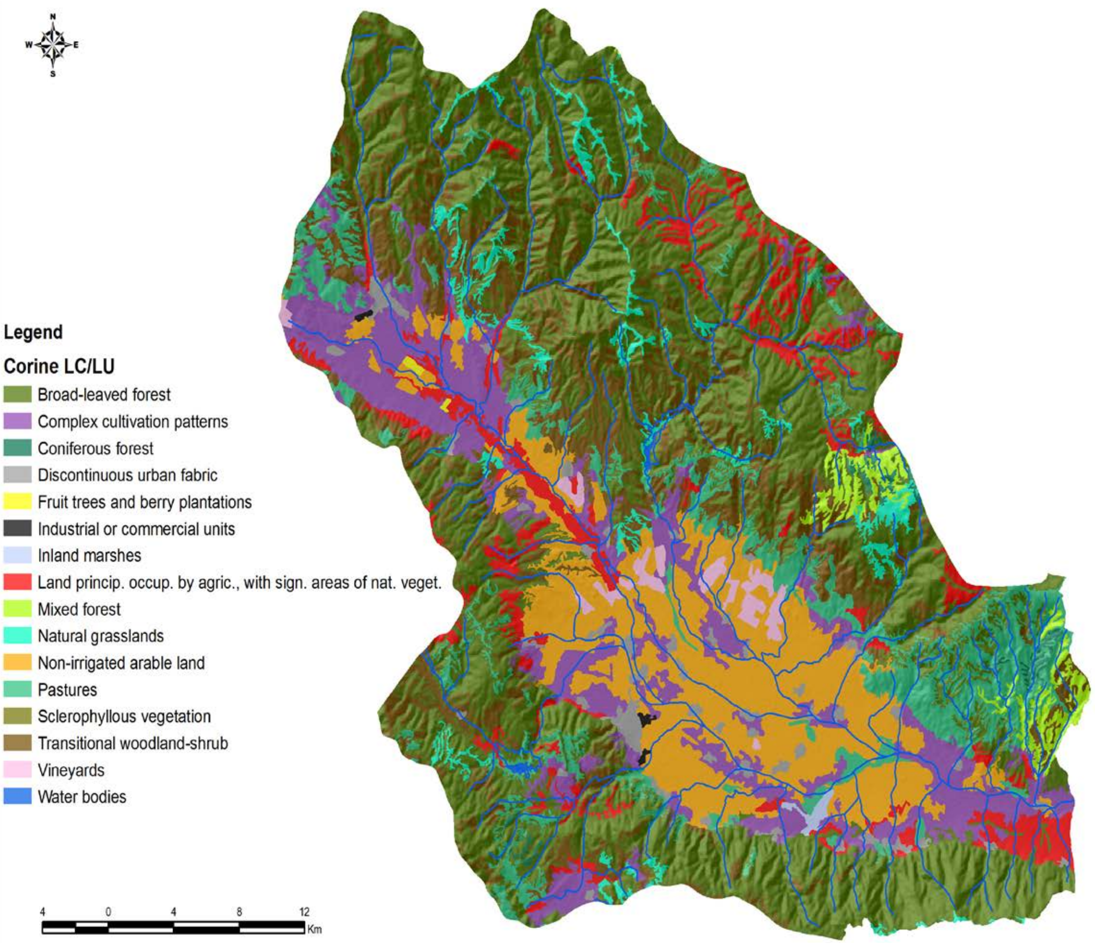

Figure 6: CORINE Land Cover map of Strumica river basin.

Type of land cover/use	Area (km^2)
Broad-leaved forest	599.71
Complex cultivation patterns	53.77
Coniferous forest	1.25
Discontinuous urban fabric	24.63
Fruit trees and berry plantations	0.85
Industrial or commercial units	1.13
Inland marshes	2.27
Land occupied by agriculture, with significant areas of natural vegetation	89.08
Mixed forest	22.75
Natural grasslands	35.28
Non-irrigated arable land	197.29
Pastures	128.31
Sclerophyllous vegetation	0.04
Transitional woodland-shrub	199.61
Vineyards	14.83
Water bodies	1.21
Total:	1372.01

Table 3: Corine Land Cover data.

oxygen deficit occurs. The load of harmful substances is evident, as well as microbiological pollution.

Class IV: Strongly polluted (euthrophic) water, which in its natural state can be used for other purposes only after certain processing. The buffering capacity is exceeded, which leads to higher levels of acidity, and which affects the development of the offspring. In the epilimnion there is oxygen saturation, and in hypolimnion there is oxygen deficit. Algal blooms are common. Increased decomposition of organic matter at the same time with the stratification of the water can cause anaerobic conditions and fish death. Harmful substances emitted or released from the sediment (deposits), can affect the quality of aquatic life. The concentration of harmful substances can vary from level of chronic to acute toxicity for the aquatic life.

Class V: Very polluted (hypertrophy) water, which in its natural state could not be used for any purposes. The water has no buffer capacity and its acidity (pH value) is harmful for most of the fish species. Large problems occur with the oxygen regime, namely, saturation with oxygen in epilimnion is present, while, the absence of oxygen in hypolimnion leads to anaerobic conditions. Decomposers dominate over producers. Fish and benthic species are not present constantly. Concentration of harmful substances exceeds acute toxicity levels for aquatic life.

The overall water quality in Strumica watershed is of class III to IV, with quality improvements during springs due to higher levels of flowing water. In Strumica river basin there is only one sampling point in Novo Selo (RIMSYS, SP 64807) near the border with Bulgaria that is the outflow section of this river. Legally required water quality as well as estimated water quality for the period (1996-2025) is presented in JICA (1999). It is noted that if the proposed Water Quality Conservation Plan is implemented, river water quality will be improved to meet the legally required clases [11].

Water use

The main land use type in Strumica River watershed is agriculture. Large parts of this arable land are irrigated. According to the Expert Report on Water Resources Management (EWRM) data the designed irrigation area is estimated to 16.047 ha out of which 12.437 ha are irrigated by 7 constructed systems. According to this source the incomplete irrigation area is 3.610 ha. According to another source (Statistical Yearbook, 1997) the designed irrigation area is 21.698 ha, the irrigated area is 21.548 ha that show incomplete area of only 150 ha.

Data on water demands in different water economy sectors may be found in NEAP 1, NEAP 2, EWRM and JICA. There are differences in calculated irrigation water demand between those reference studies due to the estimation of total service area. Total water demands in Strumica river basin for irrigation, population, industry and minimum accepted flows for current condition and projected period 2020 are presented in Table 4. Total drinking water demands are defined upon the population number. The norms for cities were taken 0,300-0,400 m^3/capita/day, while the rural water supply norm was 0,25 m^3/capita/day. Waste water quantities are estimated to be 6.717.000 m^3/year (EWRM) and 6.937.135 m^3/year (NEAP 2) [12].

In Green Growth Project (GGP) developed by World Bank the water demands have been re-estimated. The Municipal water demand growth is taken equal to population natural growth rate. The projected water demands in 2025 are estimated to be 14,8 million m^3/year for population and 35,49 million m^3/year for industry. These projections for 2050 are 15,0 million m^3/year for population and 37,1 million m^3/year for industry. It can be concluded that the previous water demands estimation (NEAP, ERWRM) are overestimated.

The data from the Ministry of Agriculture, Forestry and Water Economy (MAFWE) related to irrigation show decreasing trend of irrigated area starting from 1987. On country level the irrigated area decreased from 78.778 ha in 1987 to only 15.203 ha in 2002 that is decrease of about 80%. Irrigated area is stabilized to around 22.000 ha, (Figure 7). In Strumica watershed the irrigated area is changeable and depends both on irrigation system technology and on farmers' water demands, (Table 5). It is shown that out of total planned area of about 12.000 ha in average only about 1.500 ha are irrigated.

The irrigation technologies in Strumica watershed by municipalities is shown in Tables 3-6. It is obvious that surface irrigation participate with over 50% comparing to the sprinkler or drip system [13].

Water Balance Model

The watershed is defined by its surface water catchment area and can be viewed as being composed of two separate but inter-related components; a surface drainage area defined by topography and a subsurface region defined by soil and bedrock features. In spatial terms, the areas and boundaries of each component may not be coincident implying that regional groundwater inputs and outputs to the watershed area may occur. Based upon these factors, a general expression for the watershed water balance on a region basis can be expressed as a change in storage and may be written as input-output=change of storage, or:

$$S_t+(P+Q_{in}+G_{in})-(E+ET+Q_{out}+Q_{ws}+Q_{ir}+G_{out})=S_{t+\Delta t}$$

where the components are:

S_t: initial water storage in the watershed at the beginning of the analyzed period; P: input water in the watershed due to precipitation; Q_{in}: input water in the watershed from another watershed; G_{in}: groundwater inflow; E: output water due to evaporation from free surface water; ET: output water due to evapotranspiration; Q_{out}: outflow water to another watershed; Q_{ws}: used water for population and industry water supply; Q_{ir}: used water for irrigation; G_{out}: groundwater outflow; $S_{t+\Delta t}$: water storage in the watershed at the end of the analyzed period.

In many instances the long term difference between groundwater

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Population and tourists	Industry	Irrigation	Minimum accepted flows	Total water demands
Current water demands				
11.510.854	32.897.600	117.941.000	13.000.000	175.349.454
Projected water demands 2020				
18.233.400	34.441.700	169.343.000	13.000.000	235.018.100

Table 4: Total water demands in Strumica river basin in (m³/year).

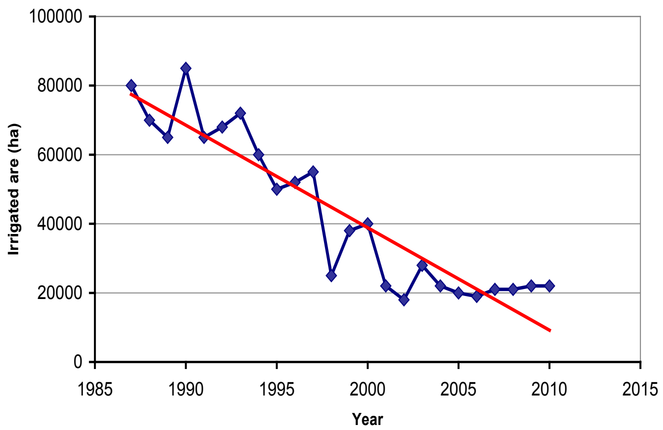

Figure 7: Irrigated area for the period 1987-2010 on country level (*Source: MAFWE*).

System	Total area	Irrigated area				
		2008	2009	2010	2011	2012
Turija	8.600	596	554	826	1227	1162
Vodoča	3.100	265	246	367	545	516
Ilovica	90	13	12	18	26	25
Novoselka	164	6	5	9	12	11
Total:	11.954	880	817	1.220	1.810	1.714

Table 5: Irrigated area in Strumica watershed in (ha).

Municipality	Sprinkler	Surface	Drip
Konche	15	40	45
Vasilevo	25	55	20
Bosilovo	24	56	20
Novo Selo	19	50	30
Strumica	29	45	26
Radovish	18	52	30

Table 6: Irrigation technologies within the municipalities in (%).

inputs and outputs are small compared to other terms, and in such conditions the water balance can be simplified by assuming the difference between groundwater input and output is essentially zero (G_{in} - G_{out}=0).

The water balance model that is developed within the Third National Communication on Climate Change presents current condition (2000/2010) year and projected condition (labeled 2025). Average monthly data for the period 1951-2010 were used as well as the projected changes in average air temperature and precipitation based on direct GCM output interpolated to geographic location of Macedonia [14].

Water balance components for current condition

The precipitation distribution in watershed is obtained by using the recorded rainfall data at Strumica meteo station for the period 1951-2010, (Figure 8). The annual precipitation sum for Strumica is 583 mm and for the watershed it increases to 688 mm. The average monthly air temperature for the watershed is obtained similarly by the recorded temperatures at Strumica for the same period, (Figure 9). It is noted that the average monthly temperature for Strumica is 12.7°C and for the watershed it is 8,8°C.

The evaporation from free surface water is computed by Penman based on air temperature data and CORINE Layers data. The computed average annual evaporation is 897,9 mm with minimum in January (12,2 mm) and maximum in July (158,9 mm). Data on evapotranspiration on watershed scale have been computed by data for Radovis and Strumica in "Characteristic of the Climatic-Vegetative-Soil Zones in the Republic of Macedonia" (Filipovski, Rizovski, Ristevski, 1996). The annual evapotranspiration is 677 mm while the minimum (6,9 mm) is in January and the maximum (123,2 mm) occurs in July [15].

The outflow from the watershed is obtained with recorded data on runoff at Novo Selo that is close to the border with Bulgaria for the period 1961-2008 with average long-term monthly distribution shown in Table 7. In Table 8 are presented monthly water demands for population and industry water supply and for irrigation.

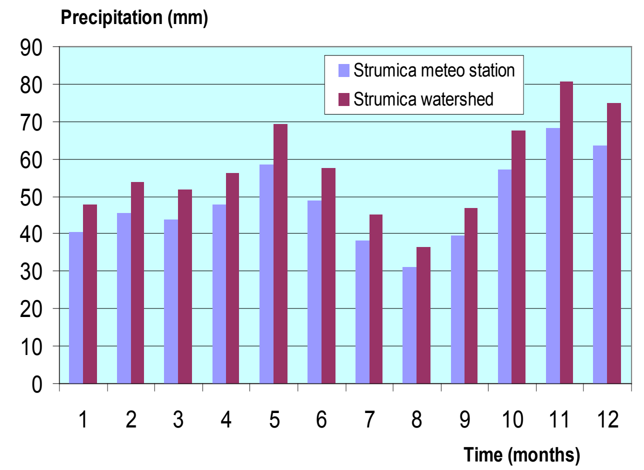

Figure 8: Monthly precipitations.

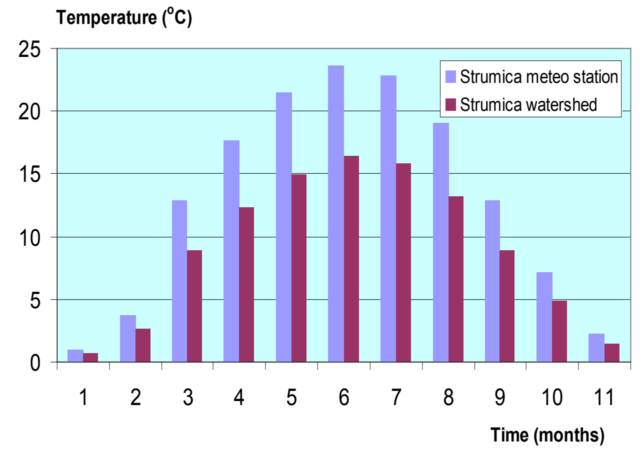

Figure 9: Monthly air temperatures.

The initial water storage in the watershed is taken 11,5 million m^3 (MCM) as annual water reserve for drinking water according to the Local Environmental Action Plan (LEAP, 2006) for Strumica region.

Projected water balance components

The annual precipitation sum in 2025 is expected to decrease for 3% and the annual air temperature will increase for 1°C according to the Climate Change Scenarios by GCM. The monthly distribution of precipitation and temperature on watershed level is obtained by data recorded at Strumica meteorological station for the period 1951-2010, (Table 9). The projected monthly temperatures, evaporation from free surface water and evapotranspiration on watershed level are presented in Table 10. The projected evaporation from free surface water is 934,2 mm that is increase of 37,2 mm (4,1%) in reference to the average current evaporation (897 mm). Evapotranspiration projection in the Strumica watershed is 706,8 mm that is increase of 29,8 mm (4,4%) in reference to the average current evapotranspiration (677 mm).

The projected outflow up to 2025 from the watershed is obtained by the runoff coefficient based on recorded runoff data at Novo Selo for the period 1961-2008. The obtained runoff coefficient in the watershed varies from 0,0153 to 0,152. The average annual runoff at Novo Selo will decrease from 3,9 m^3/s to 3,7 m^3/s or 5,1% based on GCM output.

Water balance estimates

The results out of WB model for the current condition by the use hydrological and meteorological data for the period 1951-2010 are presented in Table 11, and for the projected period up to 2025 in Table 12. Compared results of both cases/scenarios are graphically presented in Figure 10. Analysing the obtained results the following summary remarks are concluded:

1. The water balance estimates are best interpreted as illustrative of the potential character and approximate magnitudes of impacts that may result from specific scenarios of climate change. They serve as indicators of sensitivities and possible vulnerabilities. General Circulation Model (GCM) results are used in this analysis and they are not predictions that the climate will change by specific magnitudes in particular countries or regions.
2. Strumica watershed is vulnerable region in both cases/scenarios, current condition and projected condition up to 2025. During the year vulnerability is dependent of the season. Out of the irrigation season, January to May, there is no water shortage in the watershed.
3. Current condition estimates show maximum water shortage of about 360 million m^3 that is obtained in September. Water shortages are obtained for irrigation season (June to October). The average annual water shortage amounts 257,47 million m^3.
4. By the use of projected water demands up to 2025, the maximum water shortage of 478 million m^3 is obtained in September that is increase of about 25% in reference to the current condition. The annual water shortage is 388 million m^3 or increase of about 34% in reference to the current condition.
5. More reliable data in water balance modeling could be obtained if data on surface water and groundwater consumption in the watershed, especially in irrigation sector, are collected.

1	2	3	4	5	6	7	8	9	10	11	12	Annual
4.9	7.6	7.9	6.2	4.5	3.3	1.1	0.6	0.7	1.5	3.2	4.9	3.9

Table 7: Monthly runoffs of Strumica River at Novo Selo in (m^3/s).

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Population and industry												
2.2	2.2	2.7	3.6	4.4	5.3	5.6	5.6	4.4	3.6	2.7	2.2	44.4
Irrigation												
0.0	0.0	0.0	17.7	17.7	23.6	23.6	17.7	17.7	0.0	0.0	0.0	117.9

Table 8: Monthly water demands in (million m^3).

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Strumica meteo station (1951-2010)												
40.5	45.6	43.9	47.7	58.5	48.8	38.3	31.0	39.6	57.2	68.3	63.6	583.1
Strumica watershed (2025)												
46.4	52.2	50.2	54.6	67.0	55.8	43.9	35.5	45.3	65.5	78.2	72.8	667.4

Table 9: Monthly precipitation in (mm).

1	2	3	4	5	6	7	8	9	10	11	12	Annual
Strumica meteo station - temperature in (°C) (1951-2010)												
1.0	3.7	7.9	12.9	17.7	21.5	23.6	22.9	19.0	12.9	7.1	2.2	12.7
Strumica watershed - temperature in (°C) (2025)												
0.7	2.9	6.1	10.0	13.7	16.6	18.2	17.6	14.7	10.0	5.5	1.7	9.8
Strumica watershed - evaporation in (mm) (2025)												
12.2	27.1	57.5	94.6	128.4	143.5	166.6	139.4	88.6	48.4	18.8	9.2	934.2
Strumica watershed - evapotranspiration in (mm) (2025)												
7.0	19.3	44.0	74.5	100.3	111.0	129.6	106.2	65.4	33.8	11.3	4.4	706.8

Table 10: Monthly temperature, evaporation and evapotranspiration.

Month/Days	P (MCM)	E (MCM)	ET (MCM)	Q_{ws} (MCM)	Q_{ir} (MCM)	Q_{out} (MCM)	Storage (MCM)
Initial water storage							11.50
1/31	83.73	0.01	10.27	2.22	0.00	13.11	69.62
2/28	94.29	0.03	28.22	2.22	0.00	18.46	115.01
3/31	90.68	0.07	63.71	2.66	0.00	21.05	118.27
4/30	98.67	0.11	106.90	3.55	17.69	15.99	72.80
5/31	121.00	0.15	142.87	4.44	17.69	12.08	16.72
6/30	100.79	0.17	157.16	5.33	23.59	8.45	-77.02
7/31	79.25	0.19	182.84	5.55	23.59	2.95	-212.70
8/31	64.17	0.16	149.64	5.55	17.69	1.55	-322.97
9/30	81.81	0.10	92.48	4.44	17.69	1.85	-357.62
10/31	118.21	0.06	48.29	3.55	0.00	4.05	-295.29
11/30	141.19	0.02	16.34	2.66	0.00	8.19	-181.30
12/31	131.40	0.01	6.50	2.22	0.00	13.14	-71.76
Annual	1,021.34	1.09	1,005.22	44.41	117.94	121.66	-257.47

Table 11: Water budget of Strumica watershed – current condition.

Month/Days	P (MCM)	E (MCM)	ET (MCM)	Q_{ws} (MCM)	Q_{ir} (MCM)	Q_{out} (MCM)	Storage (MCM)
Initial water storage							11,50
1/31	81.22	0.01	10.32	2.63	0.00	12.71	67.03
2/28	91.46	0.03	28.61	2.63	0.00	17.91	109.34
3/31	87.96	0.07	65.26	3.16	0.00	20.42	108.47
4/30	95.71	0.11	110.55	4.21	25.40	15.51	48.47
5/31	117.37	0.16	148.96	5.27	25.40	11.72	-25.47
6/30	97.76	0.17	164.75	6.32	33.87	8.20	-140.85
7/31	76.88	0.20	192.38	6.58	33.87	2.87	-299.68
8/31	62.24	0.17	157.62	6.58	25.40	1.50	-428.55
9/30	79.36	0.11	97.13	5.27	25.40	1.80	-478.78
10/31	114.66	0.06	50.25	4.21	0.00	3.93	-422.51
11/30	136.95	0.02	16.82	3.16	0.00	7.94	-313.48
12/31	127.46	0.01	6.58	2.63	0.00	12.75	-207.99
Annual	990.70	1.13	1,049.25	52.68	169.34	118.01	-388.21

Table 12: Water budget of Strumica watershed – projection 2025.

Without these data the obtained and estimated water balance components may be taken as approximate and even overestimated considering the problems in irrigation and management practices and recent data on significant decrease of irrigated area on country level to only about 22.000 ha and in Strumica watershed to about 2.000 ha. This situation with missing and/or unavailable data should be resolved by better management with the existing irrigation systems, better monitoring, and by mapping/inventory of the individual irrigation wells.

Vulnerability Assessments

This report on regional vulnerability assessment in south-eastern part of Macedonia focuses on hydrology and water resources. Considering the important role of water to the ecosystems it is noted that the obtained vulnerability assessment is related to the ecosystems as well. Ecosystems are of fundamental importance to environmental function and to sustainability, and they provide many goods and services critical to individuals and societies. This goods and services include: (i) providing food, fibber, energy and medicines; (ii) processing and storing carbon and nutrients (iii) assimilating wastes; (iv) purifying water, regulating water runoff and moderating floods (v) building soils and reducing soil degradation (vi) providing opportunities for recreation and tourism (vii) housing the Earth's entire reservoir of genetic and species diversity. In addition, natural ecosystems have cultural, religious, aesthetic and inherent existence values. Water is an essential component of the ecosystems where the humans play important role. Therefore, water availability is an essential component of welfare and productivity.

The assessment of regional vulnerability is necessarily qualitative due to uncertainties regarding the sensitivities and adaptability of natural and social systems. In a number of instances, quantitative estimates of impacts of climate change can be found. Such estimates are dependent upon the specific assumptions of future climate changes, as well as upon the methods and models applied in the analyses. To interpret these estimates, it is important to have in mind that the uncertainties regarding the character, magnitude and rates to future climate change remain. These uncertainties impose limitations on the ability of scientists to project impacts of climate change, particularly at regional and smaller scales.

Developing countries are highly vulnerable to climate change because many are located in arid and semi-arid regions and most derive their water resources from isolated reservoirs or single point systems such as bore holes. These systems by their nature are vulnerable because there is no redundancy in the system to provide resources. There is evidence that flooding is likely to become a larger problem in many temperate and humid regions, requiring adaptations not only to droughts and chronic water shortages but also to floods and associated damages. The climate change impacts depend on the baseline condition of the water supply system and the ability of water resources managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

The Water Balance Model (WBM) for Strumica river basin has been developed in two basic scenarios: (i) current/reference condition, and (ii) projected condition up to 2025. The obtained results show that the region is vulnerable in both scenarios. Water shortage, especially in agricultural sector, is significant in summer periods. The problems that have been identified in the region are:

1. The existing irrigation schemes are characterized with poor technical condition of the structures, facilities and equipment, high water losses, low use efficiency, low capacity on cropping pattern changes, and no flow regulation in the convey structures. Reasons for such poor condition of irrigation schemes are poor or even no

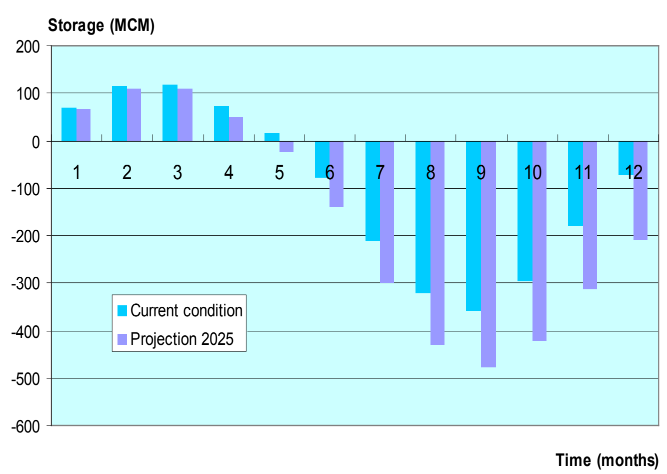

Figure 10: Water budget of Strumica watershed.

maintenance, poor quality of the hydro mechanical equipment, small size of the plots, low cost revenues collection, poor implementation of Water Law, bad financial situation of the water management organizations, rural emigration etc.

2. Another problem not only in Strumica watershed but also on country level is unregulated use of surface and groundwater. Most feasible is that farmers use groundwater as a source for irrigation. Having in mind that most of the irrigation systems are not suitable for micro irrigation, farmers find pumping of the groundwater as best option to modernize their irrigation practices. So, by the use of their "own" water source the farmer are controlling the irrigation process according to their needs as well as to the crops needs. How many individual irrigation systems are in Strumica watershed is not known. Therefore, there is an urgent need of mapping/inventory of existing irrigation wells.

3. There is no reliable data on consumed water for irrigation. Most of the irrigation schemes do not have measuring devices on irrigation intakes, river diversions or canal outlet. The price for irrigation water is defined by 1 ha of irrigated area, not on 1 m^3 consumed water. Percentage of the cost revenue collection is different and it varies from 30% to 85%. This low rate of collection of the cost revenues is one of the reasons for bad financial situation of the WMO. The price of water per crop varies in different irrigation schemes and depends on the type of the system (gravity or pumping), climate, soil conditions etc.

4. Climate variability and change in Strumica river basin is evidenced and projected by air temperature increase and precipitation decrease, although the last decade it is observed average annual temperature increase and annual precipitation sum increase. Because of such observed data the last decade may be assessed as hydrological wet period. Since 2002 storms and flash floods in the region have become more frequent and are causing significant damages.

5. The proportion of winter precipitation received as rain is increasing, with declining proportion arriving in the form of snow. Such shifts in the form and timing of precipitation and runoff are of concern to water managers in a number of settings, including irrigated agriculture, urban water supply, and flood protection. Cropping practices are likely to shift as well, perhaps towards reduced or no tilling technologies, which enhance water infiltration and conserve soil moisture, or towards irrigation technologies that are more efficient at the farm level (although not necessarily at the basin level) [16].

Conclusions

Several constraints and gaps were identifying during preparation of the thematic studies on vulnerability assessment within this study. The most persistent ones are data availability, consistency and transparency. Also there are opportunities and barriers in implementation of the proposed adaptation measures. One very important opportunity is accumulated experience to cope with droughts and floods and existing technologies in water supply and irrigation used in the country.

Proper response in the water resources sector as one of the most vulnerable to climate change requires significant financial support. Active use of the EU Framework Research Programmes and allocation of funds in the relevant institutions is recommended. Enhancement of the role of the National Climate Change Committee is recommended for coordination of climate change activities. There are some other barriers such as low investment in research, shortage of well-qualified and trained personnel for adaptation measures implementation, shortage relevant database and GIS layers in appropriate scale and others mainly on systemic and institutional level.

Implementation of some proposed adaptation measures requires the development of water resources models. There are three basic types of models: hydraulic (biophysical process models describing stream flow, flooding), hydrologic (rainfall-runoff processes), and planning (water resources system models).

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