Sustainable development indicators: Case study for South Morava river basin

Nebojša D. Veljković

Serbian Environmental Protection Agency, Ministry of Environment, Mining and Spatial Planning, Republic of Serbia

Abstract

The subject of this research study is the elaboration and evaluation of indicators of sustainable development in the field of river basin management. The aggregate indicator entitled Ecoregion Sustainable Development Index is identified by calculation of an average value by the procedure of leveling of proportion changes of three key indicators (demographic emission index, water quality index, and industrial production index). The developed aggregate indicator of sustainable development is calculated and analyzed for South Morava river basin in Serbia, for the period from 1980 to 2010. The beneficiaries of these indicators are the experts from the field of environmental protection and water management, who should use it for elaboration of reports directed towards the creators of economic development policies and river basin management planning. Elaborated according to the given methodology, the indicator Ecoregion Sustainable Development Index is available for the decision makers on the national level, internationally comparative and it provides the conditions for further elaboration and application.

Keywords: sustainable development indicators, ecoregions, water resources management.

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The basic theoretical premise in this paper is the need for ensuring connections between the economic policy and the policy of environmental protection on all the levels of social communities and in all the sectors economy and non-economy, as well as the necessity of their integration into contemporary ecological laws. Determination of qualitative and quantitative indicators of sustainable development is a key prerequisite for the improvement of sustainable society. During the 1990s, numerous programs with the aim of elaboration of indicators of sustainable development appeared. Up to now, no method for determining indicators of sustainable development has acquired the level of general acceptance. This is why a lot of effort is being put into this field by countries and expert and scientific institutions from various fields [1].

The modern European approach to the water problem is based on the correlation of waterpower and ecological outlooks. Such integral concept anticipates ecological water dimension promoted by the Water Framework Directive (WFD) and driving force and pressure determination, as well as by the assessment of their influence on water bodies [2]. The sustainable development indicators point out all the weaknesses in the multidisciplinary field of economy, environment and society, and should be used to solve the problem. Establishment and enforcement of the sustainable elements of the current macro and field strategies, as well as the development of their interaction in the state sustainable development strategy process, is possible through the technical process foundation. The process includes the assessment of the economic, social and ecological situation, problem identification, establishment of investment programs, monitoring and strategy definition. Sustainable development strategy is a cyclic process; some strategy components continue through the whole cycle and follow each other, for example, information analysis, problem identification, monitoring and definition. These components should be seen as suitable bases for the sustainable development indicators creation. An example of such an indicator relating to the determination of driving forces and pressures to an ecoregion is presented in this work [3–5].

The procedure for creating a sustainable development strategy on a national level should be based on the existing strategies and evaluations. Each comprehensive strategy, for example the economic policy and water policy, may be a good starting basis for the sustainable development state strategy. In regard to the technical aspect of the sustainable development state strategy formulation, in this paper the example of the usage of the ecoregion sustainable development index in the South Morava River Basin is given, showing that one of the most important elements of the sustainable development, water resources protection and management, can be controlled. The South Morava river basin area is 15.400 km^2 and it belongs to the Danube river basin. In the South Morava river basin area, the size of

Correspondence: Serbian Environmental Protection Agency, Ministry of Environment, Mining and Spatial Planning, Ruže Jovanovića 27a, 11060 Beograd, Serbia.

E-mail: nebojsa.veljkovic@sepa.gov.rs

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population is around 1,058,100 inhabitants, *i.e.*, 19% of the total number of Central Serbia population, “responsible” for around 25% pollution expressed in the equivalent inhabitants.

Since the international comparability in development of standardized concepts, definitions and classification of indicators is needed, the subject of research in this work is elaboration of indicators of sustainable development by methodology of aggregates of changeable indicators based on the traditional ecological and economic indicators.

METHODS

Research of ecoregion sustainable development indicators

The methodology for defining ecoregion sustainable development indicators illustrates complex interactive phenomena in the field of surface waters quality, industrial production and wastewater quantity. The changes are expressed through a serial of index numbers, representing a kind of synthesis of related phenomena. Different indicators/indexes are connected into an index number used for the comparison in time and space, using a method of calculation of some variables through their relation based on the *boundary factors principle*:

$$\text{Index} = \frac{\text{Critical value - Min value}}{\text{Max value - Min value}} \qquad (1)$$

Composite indicator key variables have been analyzed: water quality index, industrial production index and a basin demographic emission index. Such treated sustainable development indicator is called an ecoregion sustainable development index [6].

Surface waters quality index

In order to define the water quality index through its evaluation in comparison with the minimum and maximum boundary factors principles criteria, the general formula will be used (1). The calculation is based on the Water Quality Index (*WQI*) basic method as a qualification system for the assessment of surface waters quality. The *WQI* method uses index numbers within the range from 0 to 100 according to the chosen quality parameters (dissolved oxygen, biochemical oxygen demand, ammonia, pH, total oxidisied nitrogen, phosphate, suspended solids, temperature, conductivity, *Escherichia coli*), by determining the mutual factor which includes quality as a whole [7].

The arithmetic formulation for the *WQI* is of the form:

$$WQI = \sum_{i=1}^{n} q_i w_i$$

The index is derived in the case by summing the individual products of water quality rating and corresponding weighting, where *WQI* is the water quality index, and is a number on the continuous scale from 0 to 100, n – number of parameters, q_i – the water quality of the i-th parameter, w_i – the weight attributed to the i-th parameter.

This process is repeated for the n parameters (n = 10 in this exemple): dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (NH_3), pH, total oxidized nitrogen (TON), phosphate (PO_4), suspended solids (SS), temperature (T), conductivity, *Escherichia coli* and the values summed to give the *WQI*. The complete process is shown in Table 1.

With this method, the products of water quality ratings and weighting are summed; e.g. at i = 2, we have an input BOD value of 9 mg/l and the corresponding rating q_i of 15 is obtained from the BOD curve (Figure 1). By multiplying this value by the weighting, w_2 of 0.15 the weighted water quality rating becomes 2.25. The arithmetic weighed $WQI = \Sigma q_i w_i = 47.06$.

Table 1: Calculation of weighted quality ratings and WQIs: dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia (NH3), pH, total oxidizied nitrogen (TON), phosphates (PO_4), suspended solids (SS), temperature (T), conductivity, Escherichia coli

Parameter	Unit	Value	*Water quality rating, q_i*	*Weighting, w_i*	$q_i w_i$
DO	% of saturation	20.00	6	0.18	1.08
BOD	mg/l	9.00	15	0.15	2.25
NH_3	mg/l (N)	12.75	3	0.12	0.36
pH		7.50	99	0.09	8.91
TON	mg/l (N)	0.35	95	0.08	7.60
PO_4 (ortho)	mg/l (P)	0.03	94	0.08	7.52
SS	mg/l	28.00	53	0.07	3.71
T	°C	8.50	99	0.05	4.95
Conductivity	$\mu\Omega^{-1}$/cm	540.00	24	0.06	1.44
E. coli	coli/100 ml	5000	77	0.12	9.24
				$\Sigma w_i = 1.00$	$\Sigma q_i w_i = 47.06$

The time taken to calulate *WQI*s can be reduced considerably by using water quality rating Table entry that has been derived from the water quality rating curves (Figure 1 for BOD, and the figures for the other nine parameters).

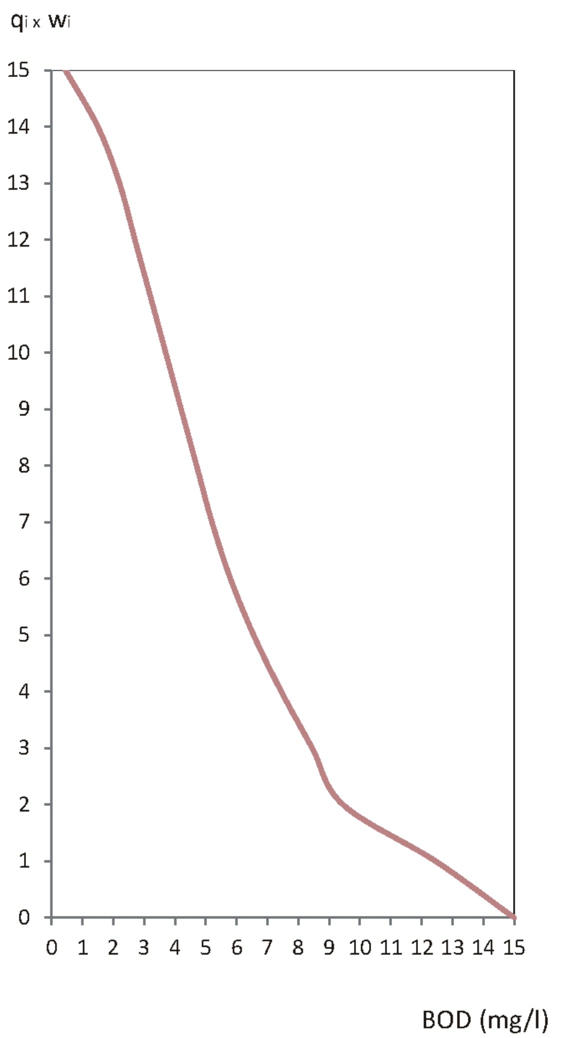

Figure 1. The water quality rating curves of biochemical oxygen demand (BOD).

Water quality calculation by *WQI* method can be easily applied using an on-line WEB application [8].

Indicator index, *WQI*, is expressed as follows:

$$WQI = \frac{\log WQI_0 - \log WQI_{min}}{\log WQI_{max} - \log WQI_{min}} \tag{2}$$

where WQI_0 is water flow quality on the measuring point expressed through the *WQI* method, WQI_{min} – minimal *WQI* value for the measuring point that is acquired by correlating the *WQI* method and minimal MCL (maximum contaminant level) values for the required water flow class, and WQI_{max} – maximal *WQI* value for the measuring point that is acquired by correlating the *WQI* method and maximal MCL values for the required water flow class at a certain profile [9].

It is necessary to calculate the *WQI* ($indexWQI_b$) for the whole basin in a research year as a composite key indicator. That is why, in the process of getting mean values, one must predict the importance of a river profile with bigger flow, as its influence on the general basin quality level is higher, expressed through the mutual indicator, the $indexWQI_b$. *WQI* indexes were pondered according to the value they have in the group structure expressed by the basin flow quality as a whole. The formula for the calculation of the group indexes through the pondered arithmetical mean value of individual indexes is as follows:

$$IndexWQI_b = \frac{(indexWQI_{1\alpha 1} + \ldots + indexWQI_{n\alpha n})}{\sum \alpha(1-n)} \tag{3}$$

where the $indexWQI_{1-n}$ are the individual indexes of the basin quality at the water measuring station, while α is the pondered factor acquired through the ratio between the average flow at the water measuring station during the significant period and the matching value of the flow at the basin exit profile.

Industrial production index

The relevant indicator for the calculation of the ecoregion sustainable development index in the field of economy is the industrial production index. This indicator links the economic activity expressed through the industrial production with the other two indicators into one index number. The industrial production index is calculated by calculating individual variables as an index with a constant base according to the general formula (1), so that we acquire:

$$IndexIND = \frac{\log IND_0 - \log IND_{min}}{\log IND_{max} - \log IND_{min}} \tag{4}$$

where IND_0 is the industrial production index with constant base for the relevant year, IND_{min} – minimal industrial production index value in the time serial during the researched period, and IND_{max} – maximal industrial production index value in the time serial during the researched period [10].

This key index is always calculated according to the same base and its units remain unchangeable, representing always the same absolute value, showing the image of the industrial production frame change for the relevant research period.

Basin demographic emission index

From the point of view of the water flow protection, it is important to reconsider quantities of the wastewater flowing from sewage systems in the basin water flow. These quantities were reconsidered having in mind the total number of citizens as demographic load in the basin area and analyzed according to the relevant flow. The index may be adjusted to the boundary factors principle, defining the relation between the waste water quantity (home used and industrial) and the average quantity during the longer period and the minimal mean monthly basin flow in relation to the total number of citizens, and expressed as follows:

$$IndexBDE = \frac{\log IR_{95} - \log DE}{\log IR - \log IR_{95}} \quad (5)$$

where $DE = Q_{ww}/P$ is a measure of the waste waters annual quantity (home used and industrial) from the sewage systems into the basin water flow per capita, $IR = Qr/P$ and $IR_{95} = Q_{95}/P$ is an average quantity during the significant period and the minimal mean monthly basin annual flow per capita (m^3/year), and P – population.

IndexBDE is named the basin demographic emission index, and represents the ecoregion sustainable management criterion.

Ecoregion Sustainable Development Index calculating method

Calculation of the composite Ecoregion Sustainable Development Index (*ESDIndex*) is based on three indicators as a group index system. Time serial of the indicator reflects the complex inter-dependent occurrences in the area of surface waters quality, industrial production, communal and demographic activities and quantity of wastewater flowing into the basin recipient. The mentioned changes are expressed through a serial of index numbers by calculating the mean value of proportional changes of the mutual index factors given in the relevant formulas (2)–(5), representing a synthesis of similar occurrences according to the formula (6):

$$ESDIndex = \sqrt[3]{\frac{indexWQI^3 + indexBDE^3 + indexIND^3}{3}} \quad (6)$$

Accurate interpretation and use of such defined composite index (*ESDIndex*) requires emphasis of its main characteristic – that it shows only the relevant changes, but gives no information on the size of the occurrence, or its composite serials. Its relative importance should be had in mind as it contains the key index of the industrial production physical frame index. The base period of the 100 index is just a momentary basis, and not the equal index level for various ecoregions, sub-basins or basins on the same national and international level.

CALCULATION AND DISCUSSION

The water quality index (*indexWQI*$_b$)

The water quality index for the whole basin (*indexWQI*$_b$) and on measuring stations (*indexWQI*$_a$) show occurrence continuance in the basin quality complex changes expressed by the group indexes. On some basin rivers measuring stations, the quality plays a more important role than on the others, depending on the size of the local river polluter. Group indexes value pondered quality index for the whole basin of the South Morava river (*indexWQI*$_b$) clearly indicate the size of the polluter in the upriver areas, but also the river's self-purifying level (Figure 2).

In order to calculate the water quality index, data on surface waters quality were used, provided by the Republic Hydrometeorological Service of Serbia. Study frequency was based on current samples twelve times a year (once a month) on thirteen basin locations [11].

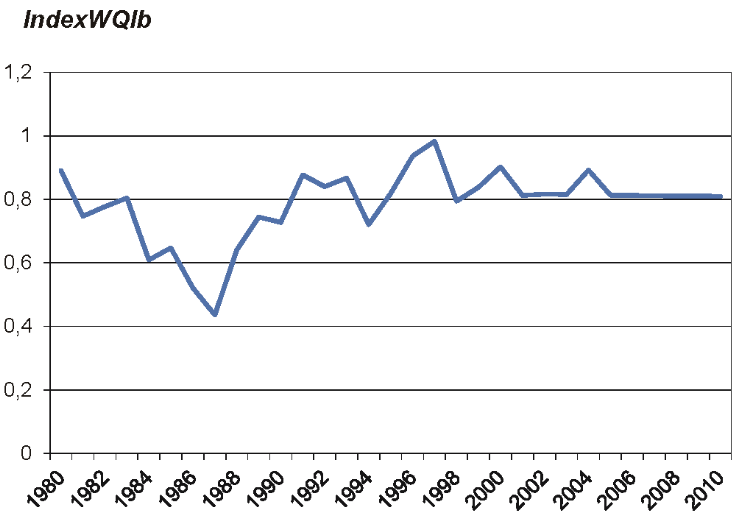

Figure 2. Water quality index at the whole basin (indexWQIb) for the period from 1980 to 2010.

The basin demographic emission index (*index BDE*)

In some Serbian regions, the major demographic changes during the previous decades resulted from various characteristic tendencies that include different economic, social and communal problems. These processes were followed by decelerated growth and changed population structure, together with great immigration, as a consequence of unemployment, war risks, and uncontrolled concentration in big regional and urban centers. Population census and estimation in the Southern Serbia ecoregion for the period 1980–2010 was done in accordance with the data from statistical almanacs (Figure 3) [12].

Wastewater influx quantities, which are, after or without any purification, poured out into the nearest water receptors in the South Morava basin, depend on the number of attached inhabitants and the user-specific water consumption, and they vary during the investigated period. The range of the general specific consumption in all sectors is 150–350 L per capita/day, not including the industrial consumption. The research has shown that during the thirty year long period, there was a growth trend of the quantity of urban, home used and industrial waste waters into the South Morava basin rivers, increased for 40% during the period from 1980 to 2010. It was a consequence of the high specific consumption of water and unrestricted usage in homes and high growth in the industrial sector. When the corresponding values of the adequate data for the inhabitants number, together with the quantity of the poured out waste waters are entered into the formula (5), basin demographic emission index (*indexBDE*) was calculated on the example of the South Morava water body for the period from 1980 to 2010 (Figure 4).

The indicator *indexBDE* defines the relation between the quantities of the wastewater emission into the basin and the competent flows expressed as the quo-

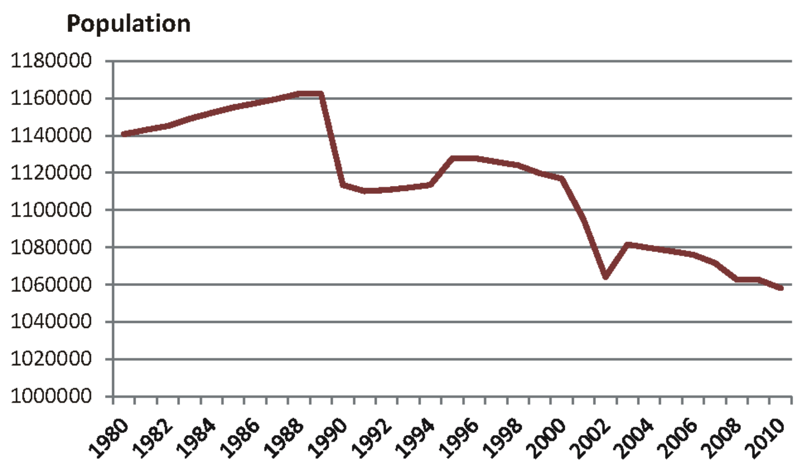

Figure 3. Population census and guess for the South Morava River basin for the period from 1980 to 2010.

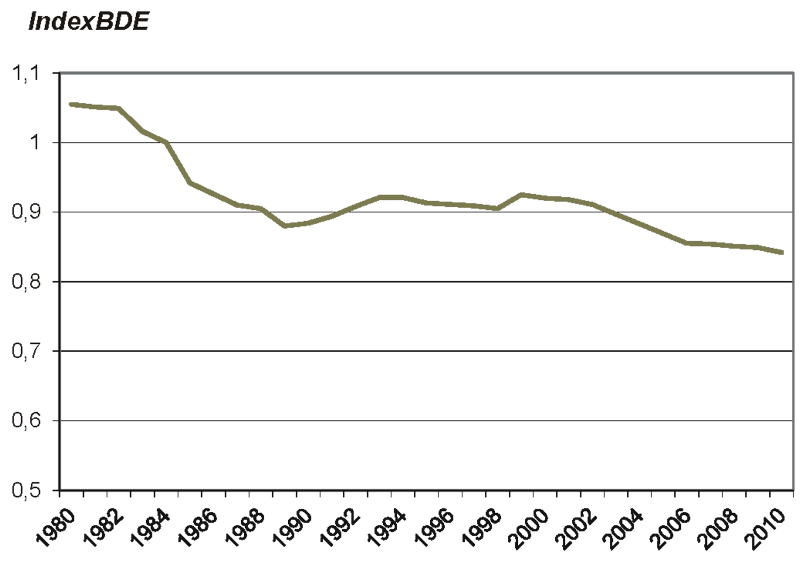

Figure 4. South Morava basin demographic emission index (indexBDE) for the period from 1980 to 2010.

tient of the minimal biological water potential and the average available water potential.

It represents the rationalization and recirculation of the previously used and emitted wastewater and its value is smaller (*indexBDE* < 1) if wastewater quantities are smaller than the competent minimal flow in a river.

The industrial production index (*indexIND*)

Tendencies toward the industrial development of the eco-agglomerations in the South Morava River Basin during the research period show that the only effective were the influences of work and capital as productive factors, while there was no technical progress as a consequence of the reduction of the productive factors general productivity. The physical extent of the industrial production as the most reliable indicator of the industrial development efficiency, expressed as *indexIND*, gives a clear picture of the industrial production reduction for eco-agglomerations in the South Morava River basin during the research period (Figure 5).

This indicator is based only on conditional physical units from the production program, and does not take into account non-qualitative and later stocks. That is why the industrial production physical extent is a more adequate indicator of water consumption in industry compared to physical product units (weight, number of pieces, length).

Calculation of the Ecoregion Sustainable Development Index for the period from 1980 to 2010

According to the competent data for the population number, waste water quantity, surface waters quality in thirteen measuring stations, and the industrial production during the period from 1980 to 2010, the appropriate formula values have been calculated from Eqs. (2)–(5), and in accordance with the formula (6), the index was calculated on the example of the South Morava River basin (Figure 6).

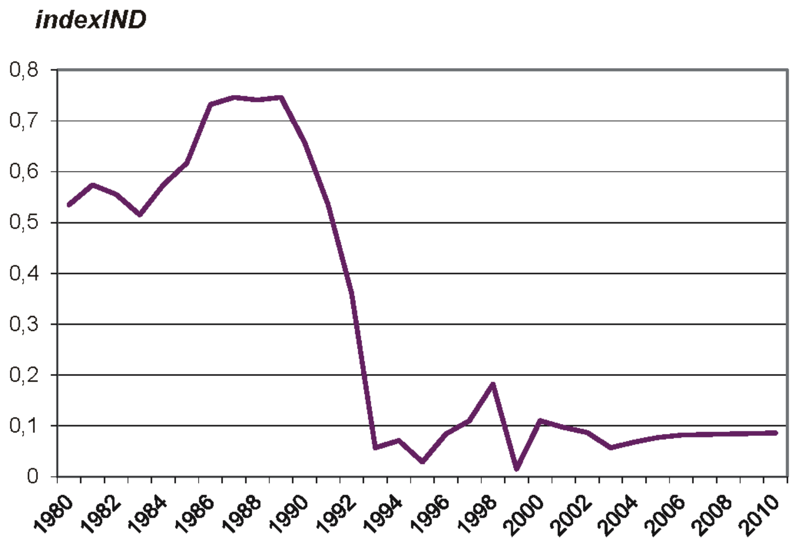

Figure 5. Indicator indexIND for the water body of South Morava basin for the period from 1980 to 2010.

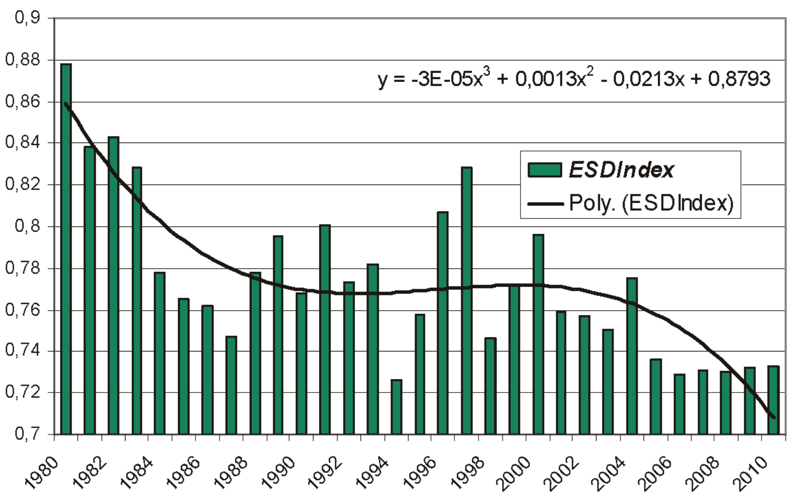

Figure 6. Diagram of the Ecoregion Sustainable Development Index trend (ESDIndex) in the South Morava basin from 1980 to 2010.

During the research period, we could clearly see the straight trend of the Ecoregion Sustainable Development Index (*ESDIndex*) of the South Morava during the period from 1980 to 2010. This trend reflexes the complex inter-reliable occurrences in the field of the surface waters quality, industrial production, communal and demographic activities, and the quantity of the emitted wastewater into recipients, showing the meaning of the sustainable development conditions during the unfavorable trends.

CONCLUSION

The research has shown that due to the mostly old fashioned technology, the water consumption in the Serbian industry, in regard to energy and resources, is very irrational and inefficient, showing a high degree of water bodies pollution through waste water emission. All macro-economic indicators during the period have shown the condition of the high economic impediment, while the water consumption in industry was not reduced in regard to the production physical extent reduction.

The calculations show a clear straight trend toward the decline of the Ecoregion Sustainable Development Index, as a sustainable development indicator, which was 0.878 for the year 1980 and 0.733 index points for year 2010. This way, the index with its development tendency shows the meaning of the negative situation of the sustainable development during the research period. The *Index* users will be experts in the field of the environmental protection and waterworks, who shall use it for their reports aimed at economic development and environmental protection policy creators, in order to make decisions and plan sustainable development concepts.

Methodological approach and testing on the real model showed that the Ecoregion Sustainable Development Index is relevant for the subject issues and scientifically substantiated, sensitive to changes in relation to space and time, justified by consistent data, understandable and measurable, expressed in the sensible way, and that the indicator of sustainable development identifies the trends which point to the direction of progress or retrogression in the concept of sustainable development.

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IZVOD

INDIKATORI ODRŽIVOG RAZVOJA: STUDIJA SLUČAJA ZA SLIV JUŽNE MORAVE

Nebojša D. Veljković

Agencija za zaštitu životne sredine, Ministarstvo životne sredine, rudarstva i prostornog planiranja, Beograd, Srbija

(Naučni rad)

Predmet istraživanja je izrada i primena indikatora održivog razvoja metodologijom agregata promenljivih činioca koji se baziraju na tradicionalnim ekološkim i ekonomskim indikatorima. Agregatni indikator pod nazivom indeks održivog razvoja ekoregiona je dobijen izračunavanjem srednje vrednosti tri ključna indikatora. Sa ekonomskog aspekta je razmatran fizički obim industrijske proizvodnje kao indikator pokretačke sile (eng. *driving force indicator*), drugi indikator pokretačke sile je sa ekološkog aspekta i definiše demografski rast u funkciji količina ispuštenih otpadnih voda i merodavnog proticaja recipijenta. Treći indikator je kvalitet vodotoka vodnih tela kao direktna posledica antropogenih aktivnosti (eng. *pressure indicator*). Serija indeksnih brojeva agregatnog indikatora se kreće u rasponu od 0 do 1 tako da vrednosti indeksa prema jedinici predstavljaju napredak prema održivom razvoju, a opadanje indeksa prema nuli je suprotan proces. Ovako razvijen indikator održivog razvoja je sračunat i analiziran za ekoregion sliva Južne Morave. Istraživanje pokazuje jasno izražen pravolinijski trend pada indeksa održivog razvoja ekoregiona, pri čemu je za 1980. iznosio 0,906, a za 2010. godinu 0,733 indeksnih poena. Indeks održivog razvoja ekoregiona kao indikator održivog razvoja upućuje jasnu poruku da je dosadašnji trend opšte neefikasnosti svih proizvodnih faktora i nenamensko i prekomerno korišćenje vode i njeno zagađivanje suprotno principima održivog razvoja.

Ključne reči: Indikatori održivog razvoja • Ekoregioni • Upravljanje vodnim resursima