

GIS Technology in Environmental Protection: Research Directions Based on Literature Review

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Abstract

This article is designed to identify research directions in application of GIS technology in environmental protection through a literature review. Critical analysis has been used to determine the thematic scope and structure of environmental protection, while bibliometric study identifies research directions. The selection of journals to be investigated is based on journal profiles and scientific prestige, together with analyses of selected articles. Two groups of journals are studied for the period 2007 through 2009. The journals *Ecological Engineering*, *Environmental Research*, and *Remote Sensing of the Environment* are studied in the range of environmental protection and *Computers & Geosciences*, the *International Journal of Applied Earth Observation and Geoinformation*, and *Photogrammetric Engineering & Remote Sensing* are in the range of GIS technology.

Keywords: GIS technology, environmental protection, analysis of journals

Introduction

Problems concerning environmental protection are vast. The term “environment” has never been defined in legislation explicitly, nor can one find a definition of environmental protection. Since environmental law is made up of a patchwork of laws, one can find terms relating to various aspects of environmental protection. In the economic sciences environmental protection is defined as activities and allows for the inclusion of measures that result in cost savings, e.g. energy efficiency measures [1]. In the U.S. Environmental Protection Agency (EPA) strategy, environmental protection is defined as controlling pollution [2].

So, it seems that environmental protection refers to any activity to maintain or restore the quality of environmental media through preventing the emission of pollutants or reducing the presence of polluting substances in environmental media. It may consist of [3]:

- (a) changes in characteristics of goods and services
- (b) changes in consumption patterns
- (c) changes in production techniques
- (d) treatment or disposal of residuals in separate environmental protection facilities
- (e) recycling
- (f) prevention of degradation of the landscape and ecosystems

A geographic information system (GIS) is a term introduced in the latter half of the 1960s by Roger Tomlinson [4]. The reference literature on geographic information systems uses numerous definitions of them formulated at various approaches, e.g. GIS is a toolbox, GIS is an information system, GIS is an approach to science, GIS is a business [5]. Broadly, GIS encompasses methods, technical means (including hardware and software), spatial data base, organization, financial resources, and people interested in its functioning [6].

Geographic information systems are also termed spatial information systems (SIS) and land information systems

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(LIS); this terminology is connected to the area and the scope of detail. Another GIS specification has geoinformation systems as those systems that handle processes relating to geoinformation, or information acquired through interpretation of geospatial data pertaining to spatial objects connected with the Earth surface. Geoinformation is additionally termed geographic information, spatial information, geospatial information, land information, and environmental information [7].

Nowadays, independent GIS systems are built increasingly rarely. More often, they are one of the components of different specialist information systems. Therefore, the concept of GIS technology finds application more often, construed as a set of methods and techniques serving to build geographic information systems [8]. These are methods and techniques including, *inter alia*: geodesy, cartography, remote sensing, and photogrammetry, as well as global positioning systems (GPS).

GIS technologies have been widely applied at all scientific fields and practical activities. With environmental management, their use includes a broad spectrum including as a simple formula, and visualization of natural data as maps of animate nature resources, visualization of pollutant concentrations in the environment and their spatial distribution (e.g. in the air) [9]. Moreover, GIS is commonly used for planning and implementing environmental management processes, e.g. water divide areas [10], hazard monitoring, area usage modeling [11], or forest protection against hazards [12]. To monitor the environmental status, various data can be retrieved, taking advantage of sensors and remote sensing measuring instruments, thus permitting comprehensive examination of the condition and changes occurring within the natural environment and its valorization [13], protection, and revitalization. According to the literature [14], using GIS methods can help evaluate natural resources; define border runs (e.g. forest divisions), and forest road networks; analyze landfill and waste dumping areas, including their footprint; plan investment locations; develop noise maps; and delineate protected areas.

GIS is applied to analyze and image data of a random nature such as flood risks, disease incidence, pest gradation, etc. For protected areas and beyond, GIS takes advantage of identifying the susceptibility of natural elements to human impact [15] and to managing forest and water resources [16]. GIS is deployed, too, to monitor environmental conditions, including, *inter alia*, lake eutrophication [17], invasive plants, and for spatial planning to reflect, e.g. wind-farm locations in relation to environmental assessment requirements [18]. Advanced spatial analyses serve to carry out comprehensive, multi-factor analyses of past and present events and forecast and examine future conditions, thus being of extreme importance to estimate natural hazards [19].

The authors of this article do not know any similar literature research designed to run a bibliometric analysis of the body of literature on GIS technology deployment to protect the environment.

Considering the fact that GIS and other geoinformatics technologies should rank high in human monitoring of the

environment, the assumption can be made that the subject matter of the research should focus mainly on air, soil and water pollution analysis, and identification of damage scales in the case of natural calamities as well as those caused by human economic activities.

Materials and Methods

In order to select periodicals for research into the application of GIS technology in environmental protection, a list of periodicals of international reach was taken from the Journal Citation Reports (JRC), available in Science Editions.

The JRC offers a systematic, objective means to critically evaluate the world's leading journals, with quantifiable statistical information based on citation data. By compiling articles' cited references, JCR Web helps to measure research influence and impact at the journal and category levels, and shows the relationship between citing and cited journals [20].

Two groups of journals are studied:

- 1) in the range of environmental protection: environmental sciences, environmental management, monitoring of environment, land use planning,
- 2) in the range of GIS technology: searching categories such as computer science, geography, geosciences, remote sensing

Based on the periodical title, 40 journals were selected: 20 journals in the range of environmental protection: *Atmospheric Environment, Agriculture and Environmental Sciences, Computers Environment and Urban Systems, Critical Reviews in Environmental Science and Technology, Ecological Engineering, Environment and Planning D-Society and Space, Ecosystems and Environment, Environment and Urban Systems, Environmental and Engineering Geoscience, Environmental Impact Assessment Review, Environmental Modelling and Software, Environmental Studies and Management, Environmental Research, Environmental Pollution, Forest Ecology and Management, Global Environmental Changes, Remote Sensing of Environment, Journal of Environmental Sciences, Acta Oecologica, and Science of the Total Environment.*

20 journals in the range of GIS technology: *Applied Geography, Cartographic Journal, Computational Geosciences, Computers and Geosciences, Earth-Science Reviews, Geoforum, Geoinformatica, Geosciences Journal, Geotechnique, Giscience and Remote Sensing, IEEE Geoscience and Remote Sensing Letters, IEEE Transactions on Geoscience and Remote Sensing, International Journal of Applied Earth Observation and Geoinformation, International Journal of Earth Sciences, International Journal of Geographical Information Science, International Journal of Remote Sensing, Journal of Earth System Science, Journal of Geographical Systems, Journal of Geography, and Photogrammetric Engineering and Remote Sensing.*

From these, the general characteristics of research themes were examined in order to choose 6 environmental

Table 1. List and characteristics of environmental protection journals for research.

No.	Title of journal	Subjects and source	Frequency	IF 2009
1	Critical Reviews in Environmental Science and Technology (CRST)	Waste and wastewater treatment, bioremediation, soil contamination, wetland function and design, recycling: air, soil, and water contaminant biogeochemistry, risk assessment and management, environmental toxicology and epidemiology http://www.tandf.co.uk/journals/titles/10643389.ass [access 14.03.2011]	bimonthly (2007, 2008); monthly (2009)	7.091
2	Ecological Engineering (EE)	Habitat reconstruction, ecosystem conservation, stream and river restoration, wetland restoration and construction, reclamation ecology, wetland creation and restoration, global climate change, alternative energy policies, ecological economics, environmental conservation, and global geopolitics http://www.elsevier.com/wps/find/journaldescription.cws_home/522751/description#description [access 14.03.2011]	monthly	2.745
3	Environmental Research (ER)	Toxic effects of environmental agents on humans and animals, the etiology of environmentally induced illness and to increase understanding of the mechanisms by which environmental agents cause disease http://www.elsevier.com/wps/find/journaldescription.cws_home/622821/description#description [access 14.03. 2011]	9 per year (2007, 2008) 8 per year (2009)	3.237
4	Journal of Environmental Sciences (JES)	Environmental chemistry, environmental biology, ecology, geosciences and environmental physics, applied research on atmospheric, terrestrial and aquatic environments, pollution control and abatement technology, conservation of natural resources, environmental health and toxicology http://www.elsevier.com/wps/find/journaldescription.cws_home/709941/description#description [access 7.03.2011]	monthly	1.412
5	Remote Sensing of Environment (RSE)	Agriculture, forestry and range ecology, earth and environmental science geography, land information geology, geoscience hydrology, water resources image processing and analysis sensor systems, and spectral-radiometric measurements http://www.elsevier.com/wps/find/journaldescription.cws_home/505733/description#description [access 14.03.2011]	4 per year (2007) monthly (2008, 2009)	3.612
6	Science of the Total Environment (SSTE)	Pollution of air, water, soil; natural and human-induced environmental changes at a global level; environmental risk management; remediation and treatment and environmental policy appraisal; novel techniques and methods of chemistry and biochemistry applicable to environmental problems; and environmental health http://www.elsevier.com/wps/find/journaldescription.cws_home/503360/description#description [access 9.03.2011]	24 per year	2.905

Source: Own elaboration based on: 1) 2009 JCR Science Edition; 2) Websites of selected journals.

protection journals and 6 GIS technology journals for detailed study: these are listed in Tables 1 and 2. Detailed characteristics of the thematic scope and scientific prestige factor – impact factor (IF) of these journals allowed for the selection of 6 periodicals for bibliometric research into GIS technology in environmental protection problems. These journals are highlighted in Tables 1 and 2 by a darker background and more detailed characteristics relating to publication frequency and website source.

To carry out research, scientific references methodology was used. Scientific magazines rank very high in promoting science. They provide a platform for investigating how professionals and researchers in a given discipline develop their interests, where various disciplines tend to go and how work themes diversify. Among scientific research methods, qualitative and quantitative approaches can be pinpointed. Quantitative methods (mathematics, statistics) provide a supportive role to scientific findings and cannot supplement analysis of studied subjects. This is why the article is based on the method of literature review as a qual-

itative approach and the bibliometric method as the quantitative approach.

The literature review as a scientific examination method is used to review scientific works and for peer review. The essence of peer review is to adjust a new problem to the extant knowledge, thus analysis and criticism of the subject literature is indispensable. The objectives and functions of the literature review are: description and evaluation of current knowledge for a given topic (research status) and arranging the knowledge [21].

Bibliometry or bibliometrics is treated in the reference texts as a research method or discipline (scientific subdiscipline). This article treats it as a research method (bibliometric method). By the same token, bibliometry is a statistical application for quantitative studies of facts, phenomena, and processes related to texts and information [22].

Due to high differentiation of environmental aspects it is assumed that the topic scope will be indicated for which a classification will be conducted to determine substance contents of articles published in adopted journals in 2007

Table 2. List and characteristics of GIS technology journals for research.

No.	Title of journal	Subjects and source	Frequency	IF 2009
1	Computers and Geosciences (CG)	New computational methods for the geosciences, geoscience information infrastructure, collection, representation, management, analysis, visualization, software development, scientific and social use of geoscience information, database, software application, web service http://www.elsevier.com/wps/find/journaldescription.cws_home/398/description#description [access 28.12.2010]	monthly	1.142
2	GeoInformatica (GI)	Geography, geographical information systems and cartography data structures, cryptography and information theory, computer science, general information storage, and retrieval multimedia information systems http://www.springerlink.com/content/100268/ [access 27.12.2010]	quarterly	1.225
3	International Journal of Applied Earth Observation and Geoinformation (IJAEOG)	Geoinformation capturing, databasing, visualization and interpretation of data, issues of data quality and spatial uncertainty http://www.elsevier.com/wps/find/journaldescription.cws_home/622741/description#description [access 28.12.2010]	bimonthly	1.776
4	International Journal of Geographical Information Science (IJGIS)	Cartography computation, computer science (general), Earth sciences, geographic information systems, location-based services, navigation systems and computer architecture of databases, topography transport geography http://www.informaworld.com/smp/title~content=t713599799~tab=sample~db=all [access 29.12.2010]	monthly	1.533
5	Journal of Geographical Systems (JGS)	Regional science, geographical information systems and cartography, computer applications in social and behavioral sciences landscape, regional and urban planning quantitative geography, simulation and modeling http://www.springerlink.com/content/103079/ [access 27.12.2010]	quarterly	1.278
6	Photogrammetric Engineering & Remote Sensing (PERS)	Employing photogrammetry, remote sensing, spatial information systems, computer vision http://www.asprs.org/PE-RS-Journal/ [access 29.12.2010]	monthly	1.110

Source: Our elaboration based on: 1) 2009 JCR Science Edition; 2) Websites of select journals.

through 2009. The layout of main theme in the field of environment protection was based on personal experience and literature data [23, 24].

The thematic scope of environmental protection is organized into 4 thematic areas and 24 thematic units.

Thematic Scope of Environmental Protection

I. General bases

1. Basic terms (environment as a subject, object and process)
2. Problems of environmental management (natural resources, functions of the environment, nature protection)
3. Historical use of the environment (impact on environment)
4. Changes of global environmental conditions (global changes of water, air, and soil conditions)
5. Ecological crisis (dimensions of the ecological crisis)

II. Environmental issues

6. Global warming (the greenhouse effect: causes, consequences, prevention)
7. Destruction of the ozone layer (causes and effects of ozone loss, protection of the ozone layer)

8. Threats to biodiversity (causes and rate of species extinction, threats to the species, protection motives)
9. Degradation of soils (types of degradation, soil erosion, desertification)
10. Threats to the forests (the role of forests in the biosphere, threats to forests and their origins)
11. Water deficiency and contamination (water circulation and resources, water contamination, types and sources of contamination, effects of contamination)
12. Medical consequences of environmental degradation (civilization-related diseases, health effects of physical changes in the environment - noise and vibration, ionizing radiation, the impact of environmental chemicalization on health conditions, the ways of interaction of pollutants with the human body, chemicals and human health)

III. Activity for environmental protection

13. The motives and the idea of environmental protection (the idea of conservation, legal and administrative nature protection)
14. Sustainable development (objectives, principles, problem of ecological scale of management)
15. Legal and organizational background of environmental protection (establishment of the legal person, liability)

- 16. Economic aspects of environmental protection (valuation of resources and environmental assets, measurements of the development)
- 17. Resources for environmental protection (legal, administrative, and economic instruments, fees, taxes, subventions)
- 18. Technology in environmental protection (energy-saving technologies, material-saving, waste-free, clean energy sources, recycling, environmental protection equipment)

IV. Humanistic aspects of environmental protection

- 19. Social dimension of environmental protection (environmental awareness, ecological conflicts, opportunities of developing environmental awareness)
- 20. Eco-philosophy (philosophical, humanistic, deep ecology)
- 21. Environmental ethics (ethics of animal liberation, rules and dilemmas of environmental ethics)
- 22. Religious aspect of environmental protection (religion versus ecological crisis, folk beliefs versus church)
- 23. Environmental protection in culture and art (ecological art, literary inspirations)
- 24. Environmental education (ecological education goals, educational projects)

Results

Articles selected for journal studies were analyzed using the literature review method, matching bibliographic descriptions of specific articles and thematic units contained in thematic areas of environmental protection. Then, using the bibliometric method, a quantitative breakdown was made for individual thematic units and areas of GIS in environmental protection (EP). Research directions based on the literature are shown in Table 3, while their graphic visualization is indicated in Fig. 1.

It can be seen from Table 3 that the articles connected with GIS technology in environmental protection, in the period in the selected periodicals in the range of environ-

mental protection (in short: EP) and in the range of GIS technology (in short: GIS), mostly involved the following thematic areas:

- 1) environmental issues: 188 articles – 120 articles EP and 68 articles GIS, including most found thematic units:
 - threats to the forests: 70 articles – 42 articles EP and 28 articles GIS
 - water deficiency and contamination: 37 articles – 20 articles EP and 17 articles GIS
 - threats to biodiversity: 33 articles – 29 articles EP and 4 articles GIS
 - degradation of soils: 24 articles – 12 articles EP and 12 articles GIS
- 2) general bases: 123 articles – 89 articles EP and 34 articles GIS, including most found thematic units:
 - changes of global environmental conditions: 65 articles – 64 articles EP and only 1 article GIS
 - problems of environmental management: 45 articles – 15 articles EP and 30 articles GIS
- 3) activity for environmental protection: 55 articles – 41 articles EP and 14 articles GIS, including most found thematic units:
 - resources for environmental protection: 19 articles EP, no articles GIS
 - technology in environmental protection: 17 articles – 9 articles EP and 8 articles GIS

In the period in the selected periodicals mostly involved in the GIS, in environmental protection articles have been published:

- in the range of environmental protection – in *Remote Sensing of the Environment* (200 articles)
- in the range of GIS technology – in *Photogrammetric Engineering and Remote Sensing* (48 articles).

Table 4 presents the total number of examined articles and articles concerning GIS in environmental protection in particular journals according to the established chronological range of 2007-09. Fig. 2 shows the share of articles on the application of GIS technology in environmental protection to total number of articles examined.

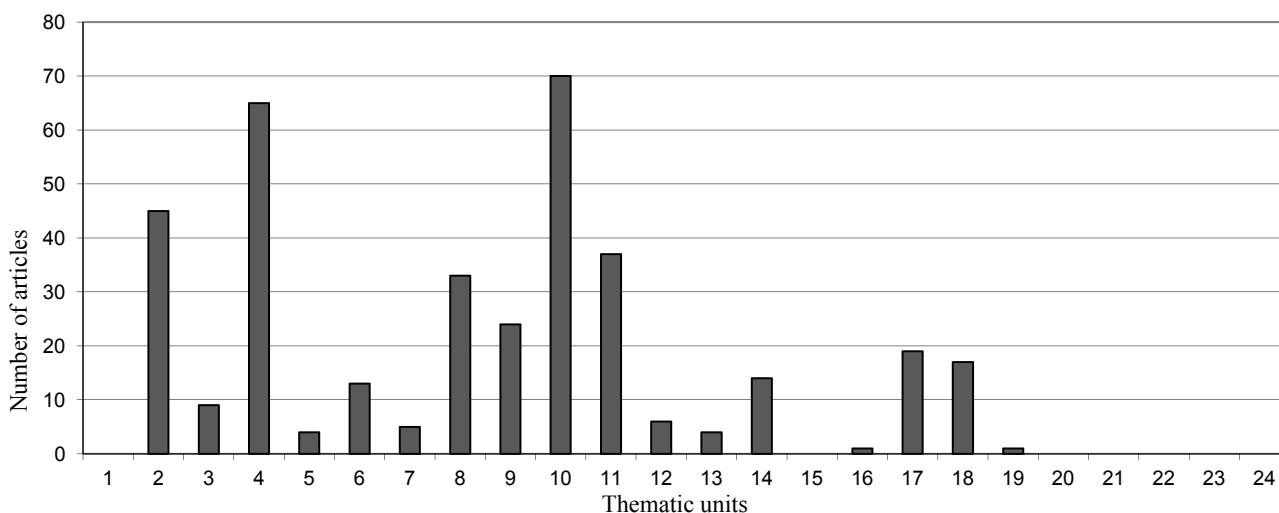


Fig. 1. GIS technology in environmental protection – quantitative outputs based on literature review

Table 3. GIS technology in environmental protection – quantitative outputs based on literature review.

Journal	CG			IJAEOG			PERS			Total in GIS journal	EE			ER			RSE			Total in EP journal	Total GIS in EP			
	2007	2008	2009	2007	2008	2009	2007	2008	2009		2007	2008	2009	2007	2008	2009	2007	2008	2009					
Topic *																								
I	1	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	0	89	123	
	2	-	-	1	-	-	12	4	10	3	30	2	-	-	-	-	-	5	6	2	15			
	3	-	-	-	-	-	-	-	-	-	0	-	-	2	1	2	4	-	-	-	9			
	4	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	1	16	25	22			64
	5	-	-	-	-	1	2	-	-	-	-	3	-	1	-	-	-	-	-	-	-			1
II	6	-	-	2	-	1	2	-	1	-	6	-	-	-	1	1	-	1	4	-	7	120	188	
	7	1	-	-	-	-	-	-	-	-	1	1	-	-	2	-	-	-	-	1	4			
	8	-	-	-	1	1	-	-	-	1	1	4	-	1	-	1	-	-	11	11	5			29
	9	2	4	3	1	2	-	-	-	-	-	12	-	-	1	-	-	-	5	2	4			12
	10	-	1	-	1	-	7	4	9	6	28	1	2	4	1	2	1	7	16	8	42			
	11	3	3	4	3	1	2	-	1	-	17	-	-	-	-	2	3	-	11	4	20			
	12	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	2	3	1	6			
III	13	-	-	1	-	-	-	-	-	1	2	-	-	-	-	-	-	1	1	-	2	41	55	
	14	-	1	1	1	-	-	-	1	-	4	-	-	-	-	-	-	2	4	4	10			
	15	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	0			
	16	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	1	-	1			
	17	-	-	-	-	-	-	-	-	-	0	10	-	2	1	-	-	1	2	3	19			
	18	-	2	-	-	1	-	2	2	1	8	-	-	-	-	-	1	5	2	1	9			
IV	19	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	1	-	1	1	1		
	20	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	0				
	21	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-			0	
	22	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-			0	
	23	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-			0	
	24	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-			0	
		6	11	12	7	7	25	10	25	13	116	14	4	9	7	7	10	56	89	55	251	367		
		29			39			48				27			24			200						

*Numbers in the Table match the thematic area and unit numbers as set forth in the scope of environmental protection.

Source: Own elaboration

Table 4. Number of examined articles.

Journal and year		CG			IJAEOG			PERS			EE			ER			RSE			
		2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009	
Article	All	104	150	217	32	43	45	83	95	83	136	108	186	171	171	131	280	330	233	2,598
	GIS in EP	6	11	12	7	7	25	10	25	13	14	4	9	7	7	10	56	89	55	367
	Rest	98	139	205	25	36	20	73	70	70	122	104	177	164	164	121	224	241	178	2,231

Source: Own elaboration

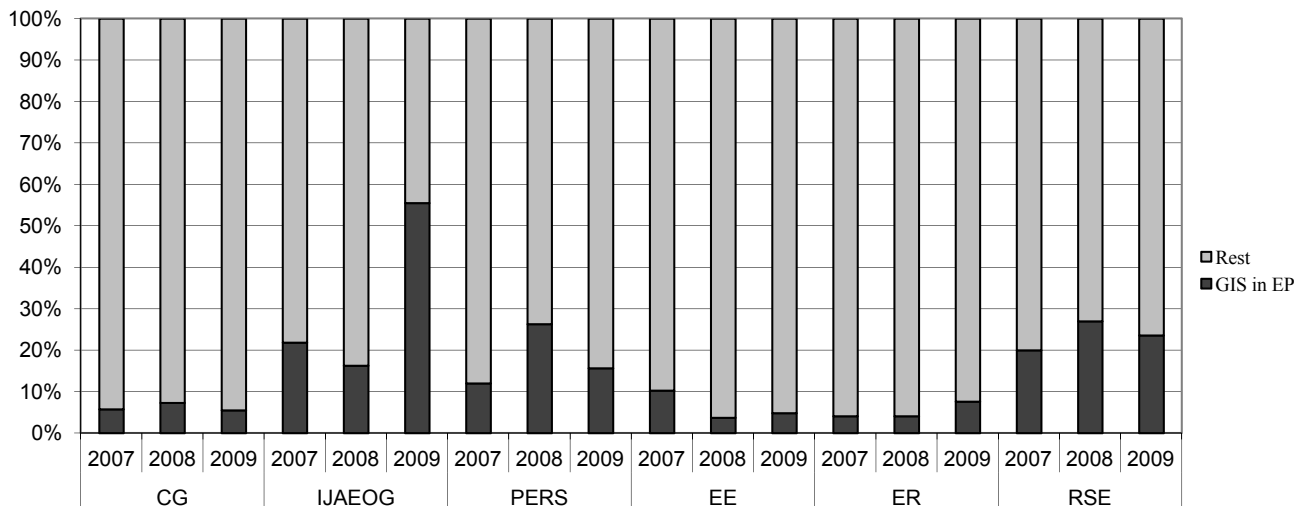


Fig. 2. Share of articles in examined periodicals about applications of GIS technology in environmental protection.

Table 4 provides the total number of examined articles, as well as the number of article examined in specific periodicals between 2007 and 2009, while their graphic percentage visualization is indicated in Fig. 2.

Conclusions

Through mostly online access to periodicals, users can easily learn the development status of various fields of knowledge.

Ongoing examination of the literature is required to complete the knowledge and follow, e.g. environmental protection development, while indicating such areas where the research is insufficient or which can have an impact on the development and formation of GIS technology in environmental protection.

Continuous examination of the literature provides the opportunity to complete the range of knowledge, as well as allowing us to indicate areas where the research, e.g. on the application of GIS technology, is insufficient, but could contribute to the development and formation of environmental protection.

From the results of bibliometric analysis, it can be seen that the research directions of GIS technology in environmental protection identified fulfil the criteria set forth in the introduction. Furthermore, analysis of the contents of articles allows us to point out detailed problems concerning relations of GIS technology issues (application of methods of remote sensing, photogrammetry, cartography, geodesy) and environmental protection in practical activities, which include:

- databases on air pollution, soil, water
- maps of natural resources
- information on the condition of the natural environment
- maps of pollutant dispersion
- models of dispersion of pollutants in the environment
- visualization of ranges of natural environment components pollution

- influence of environmental pollution on crop value
- models of distribution of environmental hazards to human health
- relations between phenomena in the environment and dangers to people
- planning reclamation of areas transformed by human activity
- distribution of natural resources
- influence of human activity on natural resources
- management of natural resources

Investigation of established specimens indicates also that issues concerning the application of GIS in environmental protection are more commonly discussed in publications on environmental protection (251 articles) than on GIS itself (116 articles). The probably is a result of the fact that environmental protection uses numerous methods that allow us to describe, identify, and monitor often very complicated processes happening in the natural environment, and GIS provides a wide range of possibilities. GIS, on the other hand, is used in many other fields; therefore, its application in environmental protection is just one of its components.

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