Environ Dev Sustain (2016) 18:1049–1057
DOI 10.1007/s10668-015-9685-3

Ecological clusters as a tool of improving the environmental safety in developing countries

E. G. Popkova[1] · L. S. Shakhovskaya[2] · S. A. Abramov[3] · A. S. Natsubidze[4]

Received: 26 February 2015 / Accepted: 16 June 2015 / Published online: 12 July 2015

Abstract The article is devoted to the research of ecological clusters as a tool of improving the ecological safety in developing countries. The authors offer to use a specifically developed methodology for determining the level of ecological security in developing countries. Formation of a city skeleton on the basis of ecological clusters, generated on the basis of biologically active natural complex, is offered. We offer the methodology of introduction of the cluster organization of the city environment with introduction models on the example of the city of Volgograd of the Russian Federation.

Keywords Ecological cluster · Environmental safety · Developing countries · City environment

1 Introduction

The state of the environment has considerably worsened since the beginning of the twentieth century, and anthropogenous influence on natural landscapes has increased (Paderewski et al. 2011; Pan et al. 2011; Pierson 2011; Korolyuk and Yamalov 2015; Ravanbakhsh et al. 2015; Gillett et al. 2015; Bolsunovskaya and Bolsunovskaya 2015). Ecology infringement has affected the quality of the environment and the comfort of

✉ E. G. Popkova
elenapopkova@yahoo.com; 210471@mail.ru

[1] Marketing Agency "MARKA," Department of World Economy and Economic Theory, Volgograd State Technical University, 11a Dvinskaya St., Apt 33, Volgograd 400087, Russia

[2] Department of World Economy and Economic Theory, Volgograd State Technical University, Volgograd, Russia

[3] Volgograd Economics and Technical College, Volgograd, Russia

[4] Faculty of the "Corporate Governance", Moscow Institute of State and Corporate Governance, Moscow, Russia

residing both in a city and in rural settlements (Ivanova 2014). It is expressed in the exhaustion of superficial and underground water sources that is especially actual for developing countries where the problem of maintenance of drinking and technical water is especially sharp. Many developing countries have vital issues with water supply, and in some countries, there are even restrictions on water use.

The issue of the territory water supply is a complex problem demanding town-planning and engineering approaches (Popkova et al. 2013b). Nevertheless, in spite of the fact that the issue of water delivery and land improvement is very urgent, today water resources are used extremely irrationally. It is especially important for the uses of rain water in the boundary regions of territories of settlements.

The current approach to the accomplishment of urban and rural territories is based on the notion of rain water's negative influence on the territory. The superficial drain will be neutralized by means of the storm water drain and system of the open or closed drainage, storm pump stations, and storm treatment facilities (Xie 2013).

There is also another approach: understanding the value of rain water as a natural resource, which can be accumulated and used for needs of a settlement. Special programs, which are a part of the plan of surface water pollution prevention, are developed to realize this approach and are obligatory to execution. The example of this is the control directive storm streams in the State of New York (Popkova et al. 2013a). Instead of the storm water drain, there is a concept management of storm streams, where a number of principles and receptions have already developed and justified themselves in work.

2 Materials and methods

The article uses the methods of structure analysis for determining the components of ecological infrastructure and relations between notions of ecological cluster, ecological infrastructure, and city infrastructure. Also, methods of systemic analysis and synergetics are used for revealing the process of formation of ecological cluster, and modeling method—for creating the model of ecological cluster. The article uses the proprietary methodology of determining the level of ecological security of territory in developing countries on the basis of determining the ratio of pollution of atmosphere and water and cleaning possibilities of forest and water treatment works, as well as determining the reserves of increasing the cleaning possibilities and minimizing the volumes of polluting emissions into environment.

3 Results

The analysis of the organization of building and accomplishment of territory with the use of storm drains has shown that creation of an ecological skeleton of the city territory should become a basis for revision of the developed principles. The city infrastructure is inseparably linked to a landscape which, in turn, can function as its component or, on the contrary, promote engineering and accomplishment destruction (Volosatova et al. 2014). Development of an ecological skeleton as a component of a city infrastructure is especially essential for cities and settlements in the southern part of Russia. The development of an ecological skeleton by reconstruction of the territories of the settlement on the basis of

introduction of ecological clusters is offered. In this article, an ecological skeleton of the territory is viewed as a spatially organized infrastructure, which supports ecological stability of territory, preventing the loss of biodiversity and landscape degradation (Boonstra and Hanh 2014).

Ecological clusters are a part of a city territory which consists of one or several biologically active kernels of a natural complex (Jia et al. 2014). A biologically active kernel provides a healthy and comfortable city environment at the expense of maintenance of a favorable microclimate (humidity, temperature, mobility of air masses), loading decrease on a city infrastructure and restoration of gardening of inhabited territories (Chakraborty and Roy 2014). Besides, the kernels of ecological clusters are a fine material for landscape architecture and they create conditions for green building (Dinica 2014). Peripheral building in the structure of the cluster also receives new impulses for modern city formation, including introduction of new types of buildings with the use of ecologically protecting technologies and the spatial solution for inhabited groups and plan the organization of the built up territories (Leathwick et al. 2010) (Fig. 1).

Formation of ecological clusters kernels as an element of a city infrastructure will allow restoring and keeping ecological well-being of the city environment (Snelder et al. 2009). The ability of kernel active elements for accumulation, recycling, and transformation of many substances is irreplaceable in the general process of self-cleaning of city territories (Begossi 2014).

3.1 Instrumentarium of monitoring and analysis of the system of management of ecological security in developing countries

It should be noted that monitoring and analysis of the system of management of ecological system in developing countries is a necessary condition for acquiring information on ecological situation in the country, prevention of natural disasters, and determination of perspectives of their elimination (Chen 2009). This is especially topical due to increase in influence on the environment in developing countries which are centers of global industrial production.

The system of monitoring of the state of ecological security in developing countries should be a place for collection, systematization, and analysis of the following data which characterize (Zeng et al. 2014; Ludwig 2012; Gündüz et al. 2011; Zhou et al. 2010):

- ecological state of territory;
- possible aggravation of ecological situation as a result of damage to environment;

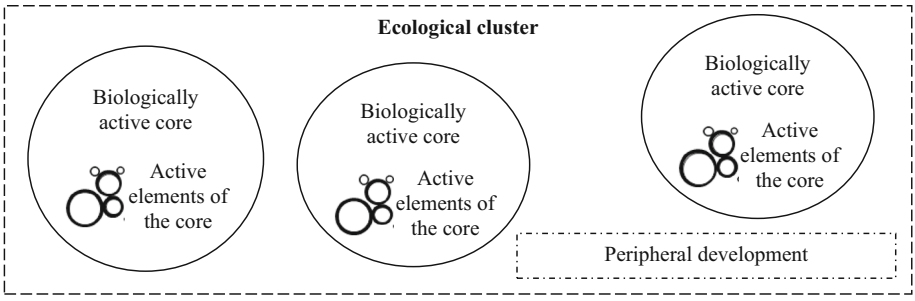

Fig. 1 Model of ecological cluster. *Source*: self-summarized

- limits of damage to environment;
- ecological reserves.

In order to determine the level of ecological security in developing countries, this research offers using the following methodology, which supposes the analysis of water and air pollution. Within this methodology, the level of ecological security of the territory is evaluated the following way:

$$ES = (EN_{air} + EN_{water}) - (EF_{air} + EF_{water}) \quad (1)$$

where ES—level of ecological security of territory; EN—current ecological state of territory; EF—perspectives of aggravation of ecological situation as a result of damage to environment.

Evaluation of ecological state of territory requires the evaluation of the level of air and water pollution according to the following scale:

Interval	1–15 %	15–30 %	30–50 %	50–70 %	>70 %
EN	5	4	3	2	1

In order to analyze the perspectives of possible aggravation of ecological situation as a result of damage to environment, it is necessary to evaluate the volume of water and atmosphere emissions. Then, the ratio of total volume of emissions into atmosphere on the given territory to the volume of emissions into atmosphere which the forests of this territory are capable to process is calculated. Depending on certain interval, the level of future air pollution will have a value from 1 to 5, according to the following table:

Interval	<1	1–1.04	1.05–1.09	1.1–1.19	1.2–1.29	>1.3
EF_{air}	0	1	2	3	4	5

In the same way, the ratio of total volume of emissions into water on the given territory to the volume of emissions into water which the water treatment works are capable of processing is calculated. Depending on certain interval, the level of future water pollution will have a value from 1 to 5, according to the following table:

Interval	<1	1–1.04	1.05–1.09	1.1–1.19	1.2–1.29	>1.3
EF_{water}	0	1	2	3	4	5

Calculation of the level of ecological security according to this methodology allows comparing developing countries to each other and to developed countries. The maximum possible value of the level of ecological security in the country within this methodology is

"10," and the minimum possible value is "8." In order to preserve the normal ecological situation in the country, it is necessary for ES indicator to be more than 0.

As an additional tool of monitoring and analysis of the system of management of ecological security of territory, this research offers to use the indicator of ecological reserves (E_{res}), which is calculated according to the following formula:

$$E_{res} = [(PL_{air} + \Delta f)/D_{min}(f) + (PL_{water} + \Delta w)/D_{min}(w)]/2 \quad (2)$$

where $PL_{air,water}$—pollution level of air and water; Δf—absolute value of unused reserves of forest expansion; Δw—absolute value of unused reserves of water treatment works; $D_{min}(f,w)$—minimal possible (potential) damage to environment (air and water) in the process of industrial production during full use of all technical and technological possibilities of country.

Potential damage to environment in the process of industrial production during full use of all technical and technological possibilities of countries is determined as volume of polluting emissions of all industrial enterprises of country, according to the formula:

$$L_{min} = \sum_{i=1,k}^{i} L_{enter} \quad (3)$$

where L_{enter}—volume of polluting emissions of all industrial enterprises of country; k—total quantity of enterprises of region.

In order to find a mode of city territories functioning, a landscape zoning is conducted; the following landscape zones are distinguished (Hortal et al. 2009): built up, built up planted trees and shrubs, vacant, vacant planted trees and shrubs, planted trees and shrubs, natural (Sanseverino-Godfrin 2015). Recommendations about percentage parity of the areas of building, coverings, and gardening are developed for each zone (Ogunbode 2013). Based on such recommendations, the specified design quantity of industrial enterprises and the scheme of the organization ecological cluster and lowering factors are accepted. The process of formation of ecological cluster is shown in Fig. 2.

The main problem of an architect is the delimitation of clusters within a self-cleared city landscape (Popkova et al. 2014). The following stage, after the definition of capacity and the area of water objects, estimates the area of a firm surface, which carries out a role of a buffer zone of kernel ecological clusters (Ji and Gunasekaran 2014). The organization of a buffer zone can be executed by means and methods of landscape architecture (Eastwood et al. 2014).

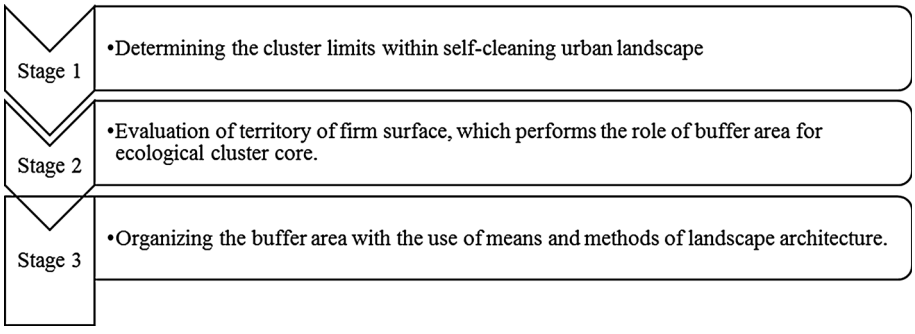

Fig. 2 Process of forming the ecological cluster. *Source*: self-summarized

3.2 Example of calculation of the demanded area of kernel ecological clusters with a small city (source: self-summarized)

Let us evaluate the level of ecological security in the Russian city of Volgograd, using the proprietary methodology. The level of air pollution is 25 %. This value is in the second interval of the developed scale, so the indicator EN_{air} is assigned the value 4. The level of water pollution is 40 %, so the indicator EN_{water} is assigned the value 3.

Total volume of polluting emissions into atmosphere on the given territory constituted 29.8 million tons in 2014. The volume of polluting emissions into atmosphere which the forests of the given territory are capable of processing constitutes 25.6 million tons. The value of the level of future pollution of air constitutes $EF_{air} = 29.8/25.6 = 1.16$; it goes into the fourth interval and is assigned the value 3.

Total volume of polluting emissions into waters of Volgograd constituted 75.5 million m^3 in 2014. The volume of polluting emissions into waters which the water treatment works of the given territory are capable of processing constitutes 66.8 million m^3. The value of the level of future water pollution constitutes $EF_{water} = 75.5/66.8 = 1.13$; it goes into the fourth interval and is assigned the value 3.

The level of ecological security of Volgograd is the following: $ES = (4 + 3) - (3 + 3) = 7 - 6 = 1$. The received value of ES is above zero, which proves the normal ecological situation in Volgograd. However, this level is critically close to zero, so it is necessary to reduce the volume of polluting emissions into water and atmosphere.

Absolute value of unused reserves of forest expansion (Δf) constitutes 11.6 million tons. Absolute value of unused reserves of water treatment works (Δw) constitutes 12.3 million m^3. Potential damage to water environment in the process of industrial production during full use of all technical and technological possibilities of Volgograd constitutes 25.4 million tons.

Potential damage to air environment in the process of industrial production during full use of all technical and technological possibilities of Volgograd constitutes 69.4 million m^3. Indicator of ecological reserves constitutes $E_{res} = (25.6 + 11.6)/25.4 + (66.8 + 12.3)/69.4 = 37.2/25.4 + 79.1/69.4 = (1.46 + 1.13)/2 = 1.29$. Consequently, Volgograd possesses 30 % reserve of improvement in ecological situation in the city.

4 Discussion

Ecological clusters allow effective settling and solving the problems of land tenure, industry, agriculture, transport, etc., according to the requirements of environmental protection. Ecological clusters open following possibilities for developing countries (Dolev and Carmel 2009):

1. Rational use of natural resources on the basis of plans of economic and environmental protection development;
2. The land tenure organization for preventing pollution and creating healthy environment;
3. Preservation of the industry development balance and ecological safety;
4. Extraction and use of ecologically safe energy, etc.

In this regard, ecological clusters represent practical interest—first, from the point of view of viable spatial planning and secondly, for sustainable development (Fig. 3).

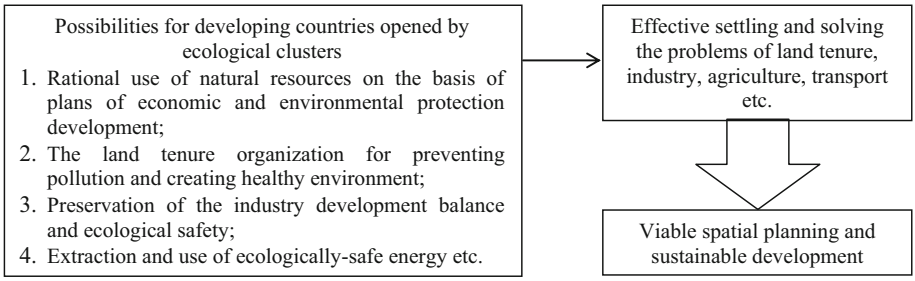

Fig. 3 Possibilities for developing countries opened by ecological clusters. *Source*: self-summarized

As a result of successful creation of ecological clusters, there is expected synergetic effect, expressed in well-balanced development of economy and ecology of developing countries (Kannan et al. 2014). This effect will increase the level of ecological security in developing countries, as it allows forming the system of management of ecological security, oriented at rational use, restoration, and development of air and water resources of the country (Snelder et al. 2008).

The further researches in the sphere of creation and development of ecological clusters can be conducted in following perspective directions (Zhang et al. 2014):

- Development of ecosystems including the serene rivers;
- Creation of green zones, allowing to counterbalance city and suburban growth;
- Efficient use of resources;
- Planning of manufacture considering the prevention of acts of nature;
- Reduction in energy consumption,etc. (Arponen et al. 2008).

These questions can be effectively solved by means of ecological clusters, created in developing countries (Vellend et al. 2008; Kilroy et al. 2008; Rodrigues and Brooks 2007). Reconstruction of the city environment, accomplishment, and engineering preparation of the territory should be developed as a unified complex of actions with the obligatory use of resources of the internal development put in a natural complex of the settlement (Nica 2010; Guisan and CanceloM 2014). The formation of ecologically steady city structures is a perspective direction of the development of the territories in developing countries (Sun 2014; Chen and Bian 2014; Luo et al. 2014; Walther et al. 2012; Bando et al. 2012).

Acknowledgments This work was executed with the financial support of the Ministry of Education and Science of the Russian Federation within the limits of a base unit of the state task (Project # 2797).

References

Arponen, A., Moilanen, A., & Ferrier, S. (2008). A successful community-level strategy for conservation prioritization. *Journal of Applied Ecology, 45*(5), 1436–1445.

Bando, D. H., Moreira, R. S., Pereira, J. C. R., & Barrozo, L. V. (2012). Spatial clusters of suicide in the municipality of São Paulo 1996–2005: An ecological study. *BMC Psychiatry, 12*, 124.

Begossi, A. (2014). Ecological, cultural, and economic approaches to managing artisanal fisheries. *Environment, Development and Sustainability, 16*(1), 5–34.

Bolsunovskaya, Y. A. & Bolsunovskaya, L. M. (2015) Ecological risk analysis as a key factor in environmental safety system development in the Arctic region of the Russian Federation. In *IOP conference series: earth and environmental science* (Vol. 24, No. 1, pp. 012003).

Boonstra, W. J., & Hanh, T. T. H. (2014). Adaptation to climate change as social–ecological trap: A case study of fishing and aquaculture in the Tam Giang Lagoon, Vietnam. *Environment, Development and Sustainability, 14*(2), 36–39.

Chakraborty, D., & Roy, J. (2014). Ecological footprint of paperboard and paper production unit in India. *Environment, Development and Sustainability, 13*(1), 56–58.

Chen, Y. H. (2009). Combining the species–area–habitat relationship and environmental cluster analysis to set conservation priorities: A study in the Zhoushan Archipelago, China. *Conservation Biology, 23*(3), 537–545.

Chen, D. H., & Bian, D. S. (2014). Research on ecological development in innovation of tourism industry cluster. *Advanced Materials Research, 962–965*, 2225–2228.

Dinica, V. (2014). Competing societal and ecological demands for groundwater: Boundary judgments and convergence mechanisms in the Netherlands. *Environment, Development and Sustainability, 16*(3), 555–573.

Dolev, A., & Carmel, Y. (2009). Distribution of threatened-unprotected vertebrates as a basis for conservation planning. *Israel Journal of Ecology & Evolution, 55*(2), 117–132.

Eastwood, J., Kemp, L., & Jalaludin, B. (2014). Explaining ecological clusters of maternal depression in South Western Sydney. *BMC Pregnancy and Childbirth, 14*(1), 47.

Gillett, D. J., Weisberg, S. B., Grayson, T., Hamilton, A., Hansen, V., Leppo, E. W., et al. (2015). Effect of ecological group classification schemes on performance of the AMBI benthic index in US coastal waters. *Ecological Indicators, 50*, 99–107.

Guisan, M. C., & CanceloM, T. (2014). Industry, productivity and development in 96 European regions, 2005–2010. *Journal of Regional and Sectoral Economic Studies, 14*(1), 69–80.

Gündüz, S., Güler, G., & Yildizci, A. C. (2011). Ecological corridors and clusters for environmental master plan and environmental management studies of Istanbul. *A/Z ITU Journal of the Faculty of Architecture, 8*(1), 229–240.

Hortal, J., Araújo, M. B., & Lobo, J. M. (2009). Testing the effectiveness of discrete and continuous environmental diversity as a surrogate for species diversity. *Ecological Indicators, 9*(1), 138–149.

Ivanova, L. A. (2014). Adaptive features of leaf structure in plants of different ecological groups. *Russian Journal of Ecology, 45*(2), 107–115.

Ji, G., & Gunasekaran, A. (2014). Evolution of innovation and its strategies: From ecological niche models of supply chain clusters. *Journal of the Operational Research Society, 55*(6), 888–903.

Jia, Z., Wu, H., Hao, M., & Xing, L. (2014). The study on remote sensing inversion of ecological environmental indices and their dynamic analysis in the six karst peak cluster areas, Guangxi. *Proceedings of SPIE—The International Society for Optical Engineering., 9158*, 91580X.

Kannan, R., Shackleton, C. M., & Shaanker, R. U. (2014). Invasive alien species as drivers in socio-ecological systems: Local adaptations towards use of Lantana in Southern India. *Environment, Development and Sustainability, 16*(3), 649–669.

Kilroy, C., Snelder, T. H., Floerl, O., Vieglais, C. C., & Dey, K. L. (2008). A rapid technique for assessing the suitability of areas for invasive species applied to New Zealand's rivers. *Diversity and Distributions, 14*(2), 262–272.

Korolyuk, A. Y., & Yamalov, S. M. (2015). Differentiation of ecological groups of species according to their reaction to moisture in differentiation of steppes of the West Siberian plain and Southern Urals. *Contemporary Problems of Ecology, 8*(2), 162–172.

Leathwick, J. R., Moilanen, A., Ferrier, S., & Julian, K. (2010). Complementarity-based conservation prioritization using a community classification, and its application to riverine ecosystems. *Biological Conservation, 143*(4), 984–991.

Ludwig, R. (2012). Massive ökologische Konsequenzen und wirtschaftliche Verteilungskämpfe | [Massive ecological consequences and economic distribution conflicts: The EU research project CLIMB in the framework of the scientific cluster CLIWASEC. Interview with Prof. Dr. Ralf Ludwig]. *GWF, Wasser—Abwasser* (Vol. 153, No. 9, pp. 912–914).

Luo, W.-Q., Zhang, H.-X., Jiang, Z.-C., Jin, K.-M., Li, Y.-Q., & Wang, Z.-G. (2014). The difference in soil erosion in different environments of karst peak-cluster depression and the study of soil erosion prevention: a case study of Guohua karst ecological experimental site, Guangxi. *Acta Geoscientica Sinica, 35*(4), 473–480.

Nica, M. (2010). Small business clusters in Oklahoma: MAR or Jacobs effects? *Journal of Regional and Sectoral Economic Studies, 10*(2), 24–31.

Ogunbode, C. A. (2013). The NEP scale: Measuring ecological attitudes/worldviews in an African context. *Environment, Development and Sustainability, 15*(6), 1477–1494.

Paderewski, J., Gauch, H. G., Madry, W., Drzazga, T., & Rodrigues, P. C. (2011). Yield response of winter wheat to agro-ecological conditions using additive main effects and multiplicative interaction and cluster analysis. *Crop Science, 51*(3), 969–980.

Pan, F., Zhang, W., Wang, K., He, X. Y., Liang, S. C., Wei, G., et al. (2011). Litter C:N:P ecological stoichiometry character of plant communities in typical Karst peak-cluster depression. *Acta Ecologica Sinica, 31*(2), 335–343.

Pierson, J.-M. (2011). Green task allocation: Taking into account the ecological impact of task allocation in clusters and clouds. *Journal of Green Engineering, 1*(2), 129–144.

Popkova, E., Akopova, E., Alekhina, E., Dubova, J., Popova, J., Avdeeva, I., & Proskurina, I. (2013a). Methodology of development of strategy of development of economic systems. *World Applied Sciences Journal, 26*(4), 489–493.

Popkova, E. G., Dubova, Y. I., Yakovleva, E. A., Azarova, N. A., & Titova, E. V. (2014). Role of ecological marketing in formation and development of ecological cluster. *Asian Social Science, 10*(23), 1–8.

Popkova, E., Morkovina, S., Patsyuk, E., Panyavina, E., & Popov, E. (2013b). Marketing strategy of overcoming of lag in development of economic systems. *World Applied Sciences Journal, 26*(5), 591–595.

Ravanbakhsh, M., Amini, T., & Hosseini, S. M. N. (2015). Plant species diversity among ecological species groups in the Caspian Sea coastal sand dune; Case study: Guilan Province, North of Iran. *Biodiversitas, 16*(1), 16–21.

Rodrigues, A. S. L., & Brooks, T. M. (2007). Shortcuts for biodiversity conservation planning: the effectiveness of surrogates. *Annual Review of Ecology Evolution and Systematics, 38*(1), 713–737.

Sanseverino-Godfrin, V. (2015) Safety and environmental control of industrial activities in France: A negotiated relationship. In *Safety and reliability: methodology and applications—proceedings of the European safety and reliability conference, ESREL 2014* (pp. 695–700).

Snelder, T., Lehmann, A., Lamouroux, N., Leathwick, J., & Allenbach, K. (2009). Strong influence of variable treatment on the performance of numerically defined ecological regions. *Environmental Management, 44*(4), 658–670.

Snelder, T. H., Pella, H., Wasson, J. G., & Lamouroux, N. (2008). Definition procedures have little effect on performance of environmental classifications of streams and rivers. *Environmental Management, 42*(5), 771–788.

Sun, P.-J. (2014). A study on SME cluster evolution models and institutional arrangements "ecological communities" perspective. *BioTechnology: An Indian Journal, 10*(10), 4572–4578.

Vellend, M., Bjorkman, M., & Mcconchie, A. (2008). Environmentally biased fragmentation of oak savanna habitat on southeastern Vancouver Island, Canada. *Biological Conservation, 141*(1), 2576–2584.

Volosatova, U., Shvagerus, P., Popkova, E., & Budanova, I. (2014). Conceptual approach to ecological information marketing system formation at the Russian market. *World Applied Sciences Journal, 30*(8), 1020–1023.

Walther, C., Lüdeke, M., & Janssen, P. (2012). Show record link row. Cluster analysis to understand socio-ecological systems: A guideline. *PIK Report, 126*, 2–90.

Xie, Y. F. (2013). Hotspots of ecological and environmental risk research in China based on multidimensional scaling analysis and cluster analysis. *Advanced Materials Research, 807–809*, 641–646.

Zeng, X.-X., Liu, Y.-G., Zeng, G.-M., Hu, X.-J., Zhang, P.-Y., & Gong, X.-M. (2014). Analysis of energetic ecological footprint and its driving effects in city cluster of Xiangjiang River basin. *Journal of Hunan University Natural Sciences, 41*(12), 115–122.

Zhang, T., Yang, W.-L., Chen, S.-J., Shi, D. L., Zhao, H., Ding, Y., et al. (2014). Occurrence, sources, and ecological risks of PBDEs, PCBs, OCPs, and PAHs in surface sediments of the Yangtze River Delta city cluster, China. *Environmental Monitoring and Assessment, 186*(8), 5285–5295.

Zhou, P., Qi, W., Feng, S., Wang, C. (2010). Analysis on the ecological equilibrium of hi-tech industrial clusters. In *2010 international conference on machine learning and cybernetics, ICMLC 2010* (Vol. 4, No. 1, pp. 1637–1641).