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ANALYSIS OF LAND USE TRANSFORMATION POTENTIAL IN SPATIAL MANAGEMENT

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Abstract

The current system of spatial planning in Poland does not provide an effective and efficient tool for controlling planning decisions at a level higher than local. The result is an unrealistic approach to adopting development policies. Nowadays there is strong competition among local governments to attract investors, which results in excessive designation of investment areas and, consequently, an imbalance between supply and demand on the real estate market. An extremely important factor from the point of view of local authorities is also the financial burden on government budgets related to the implementation of the provisions of previously adopted policies. An improper spatial development policy can therefore generate costs without delivering the expected results, due to the lack of demand for the offered resources.

A step in the right direction in optimizing how the spatial policy process is shaped may include conducting analyses and forecasts to support the decision-making process. Such analyses are needed both in terms of the amount of areas designed for each type of land use as well as their spatial distribution. Our considerations are focused on the second aspect. Analysis of land use transformation potential can be used in spatial management by selecting areas most where land use is most likely to change. The paper presents the simplified mechanisms of such analyses which can be adopted by the use of cellular automata. The final potential of an area is affected by variables such as the neighborhood, accessibility and suitability. As a result of the integration of these variables, it is possible to determine land use transformation potential. These considerations relate to the MOLAND (Monitoring Land Use/Cover Dynamics) research project and works on the development of the Metronamica decision support system, conducted in Western Europe.

Key words: *land use transformation potential, spatial policy optimization, cellular automata.*

JEL Classification: Q01, R53, R58.

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1. Spatial policy in Poland

In Poland, there is a three-step spatial planning and policy system. The national level is determined by the National Spatial Development Concept, the voivodeship level – by the voivodeship (provincial) zoning plan, and finally, at the gmina (municipal) level, by the study of conditions and directions of spatial management. This section focuses on the mechanisms influencing the formulation of local spatial policies and the effects of these activities at the supralocal level.

1.1. Mechanisms influencing the spatial policy of gminas

The shape of spatial policy of gminas is affected by various stakeholder groups, representing different opinions and arguments. The task of the local government is to balance these arguments and proposals. On the one hand, gminas strive to be ideal places for entrepreneurs to invest; on the other hand, they must also take into account public interest and the interest of the whole community.

Currently, a popularly adopted direction of activities is the development of Land Administration Systems while implementing decision support systems in order to solve complex space management problems. Globally, Land Administration Systems differ in many aspects (RAJABIFARD et al. 2007, BANDEIRA et al. 2010), but one of the basic principles is that they provide an infrastructure to implement policies and spatial strategies for achieving sustainable development (WILLIAMSON et al. 2010). These systems integrate ownership data, property values and information about land use (STEUDLER et al. 2004) so that the use of decision support systems can lead to more complex analyses. Weighing arguments in spatial conflicts involves the assessment of various components. Decision support systems are able to help assess the financial or environmental impact of specific planning solutions. A need has been noted for the simultaneous development of spatial data infrastructure along with the formulation of new spatial policies. Such action would enable a thorough analysis and evaluation of newly arising problems in real estate management (CHENG et al. 2006). A primary goal of Land Administration Systems should be the organization and management of space and real estate as valuable and limited resources, treating the systems as a base to balance economic, social and environmental factors (DAWIDOWICZ et al. 2013).

By using this type of support, local governments form spatial policies which, with the help of local laws, are implemented in reality. Creating socio-economic development is, at the same time, an important factor stimulating local investments. To obtain investors, local governments can take advantage of a variety of instruments that increase the investment attractiveness of a given area (LIZIŃSKA and ŹRÓBEK-RÓŻAŃSKA 2009). Allocating land for various forms of development is one such action. From the point of view of a particular municipality, there is the question of how much land should be designed for a certain function so that the planned investments are in fact realized. The answer may come from analyses and forecasts of future development (SALACHNA 2013) but, at the moment, these factors are not an obligatory element of the spatial policy applied in practice.

1.2. The effects of spatial policies at the supralocal level

Documents prepared on national and provincial levels define the directions of action for local policies. However, there is no efficient legal mechanism for the holistic assessment of local spatial policies in order to analyze the effects of a system functioning in such a way. In order to assess the spatial policy of the country, we can refer to data derived from analyses and reports on the state of the country's spatial development and spatial development policies. As indicated in the report "Development of Cities in Poland", developed for preparing a review of the OECD National Urban Policy in Poland, less than 1% of the country is covered by residential development (2010). However, the "Analysis of the state and conditions of planning work in gminas at the end of 2011," reveals that according to the study of the conditions and directions of spatial development of gminas, nearly 13% of the country was assigned for this purpose (2012). These data indicate a lack of realism in the assumptions made during the creation of local policies. However, they do not provide information about the anticipated thirteen times higher increase in population in relation to the current level. This involves a change in lifestyle and increasingly popular single-family housing construction, characterized by lower density living in urban areas.

However, even taking into account the local density of residential development at the level of specific cadastral units, the excessive allocation of land for these purposes can be observed. As shown in an analysis performed for Wrocław and ten surrounding gminas occupying an area that is currently home to approximately 750,000 inhabitants, areas for housing construction for over 2,500,000 people

were designated (KAZAK et al. 2013). The implementation of such an assessment on a national scale would require the integration of multiple databases and a systematic approach to monitoring activities in the field of real estate management. The need to integrate the systems of information on real estate in order to increase their efficiency and multi-tasking ability had been postulated earlier in the scientific world (ŹRÓBEK and ŹRÓBEK 2008). Still, as indicated by the above analysis, no efficient control mechanism of spatial policy on the national level has been implemented. It therefore seems reasonable to search for a solution that would support the process of creating realistic and rational spatial development policies. This goes with the direction of changes for the new decade, a direction associated with the reliance of the Land Administration System on new technologies (WILLIAMSON et al. 2010).

2. Analysis of land use transformation potential

Change of land use from one functional class to another is a process that we cannot fully describe mathematically. This is due to, among other things, people's subjective assessments or the nonhomogeneity of decisions made by the population as a whole. There are, however, some local patterns and relationships which make some kinds of land more likely than others to undergo land use changes. This section focuses on the purpose of carrying out such studies and technologies which have been used for this purpose.

2.1. The aim of analysis

In order to optimize the process of formulating spatial policies, a more realistic approach to determining the driving forces affecting land use transformation is necessary. Here, the key is the realistic estimation of the investors' demand for building sites, so as not to lead to a significant imbalance between supply and demand in the real estate market. For analyses conducted in this study, this element is an external factor, which means that the examination of the land use transformation potential does not answer the question of how much land should be designated for new projects. However, it is possible to create growth projection based on the probability of developing the individual areas. Knowledge of this probability can provide useful information in solving many problems, such as the protection of natural resources, investment in technical infrastructure or making financial predictions by administrative units.

Knowledge gained from such analyses can also be applied in creating spatial policies. To allow spatial development in municipalities, local authorities designate the areas intended for specific purposes. However, they do not often know which areas are characterized by a higher probability to be transformed by new development. This leads to designating too much land for specific uses. Following these decisions, it is often necessary to bear significant expenses associated with buying land for public development, carrying out its partition or constructing technical infrastructure. The analyses of land use transformation potential can respond to this problem, indicating which areas should be the first to be included in the implementation of the spatial policy. As a result, it will be possible to limit actions aimed at preparing land for investments that would most likely fail to be realized. It therefore seems that carrying out such analyses can be useful in the development of spatial policies of local governments, thus advantageous to the local budget and influencing the way real estate is managed.

2.2. Technologies used for analysis

Primary technologies used to make predictions on spatial development are based on two mechanisms. The first mechanism is neural networks, sometimes called genetic algorithms; the second one is cellular automata. Both technologies should be viewed as decision support systems, which means that we cannot read the results of these analyses directly. They are established for advisory and optimization reasons, and the final decision should be taken by a competent person. As learning systems, these mechanisms are based on current and historical processes. Changes in the patterns will, therefore, not be reflected in the results of such analyses. For example, calibrating the model while using Polish data from the 70s or 80s of the twentieth century will be able to duplicate the localization patterns that existed in the former system of spatial management. In order to perform reliable predictions, we must, in this case, have data from the 90s of the twentieth century and onwards, which can be useful in identifying mechanisms and patterns of land use development changes currently in effect.

Neural networks are a simplified model of the brain, consisting of a large number of information processing elements. These elements are connected by a network of parameters which are modified during the learning process. The final topological structure and parameters of individual links define how the network works. Information obtained at the output of the network is a response to the task set for the network (TADEUSIEWICZ 1993). Neural networks have a variety of applications. One of them is making predictions which can also be used in forecasting future investment location in a given area.

Cellular automata are discrete systems in temporal-spatial terms (WYCZAŁEK 2010). Each cell is assigned a specific value. These values may change in subsequent iterations if the imposed conditions are satisfied. Depending on the phenomena that we want to present, it is possible to have different patterns of changes in the cells. For example, to make things simple, we can say that while working out an evacuation plan, the mechanism will transfer the value of the cell to the neighboring free cell, so that the value representing people will move away from the area of danger as quickly as possible (BIŁOZOR et al. 2013). When modeling the spatial expansion of epidemics, we will not deal with the transfer of cell values, instead copying them to the neighboring cells. These simplified examples show the variety of mechanisms that can be defined using cellular automata.

3. Model concept of land use transformation potential analysis

Scientists point to the possibility of using both technologies, i.e. genetic algorithms as well as cellular automata, in predicting the spatial development of different forms of land use; however, they are rarely used in practice in Polish conditions. At the level of research, attention should be paid to the use of genetic algorithms for determining the optimal state of rural areas (DACKO 2002) and in the assessment of the spatial development of buildings (SZUNIEWICZ 2013). For the needs of this paper, it was decided to use cellular automata as an alternative method to the cases mentioned above. Based on the analysis of literature, three basic components affecting land use transformation potential were indicated: neighborhood, availability and suitability (Fig. 1).

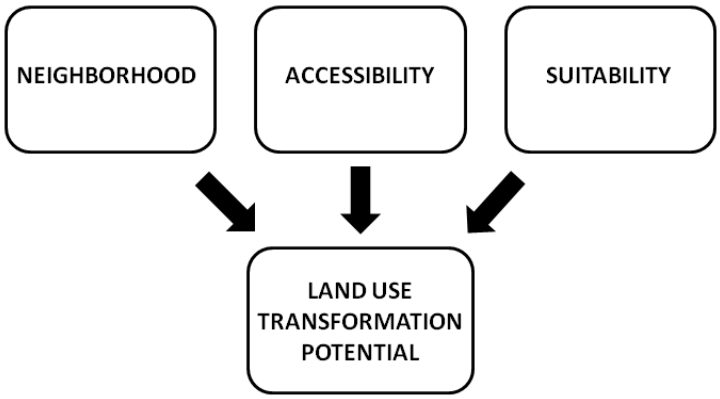

Fig. 1. Components of land use transformation potential calculations. *Source*: own study.

In order to carry out the analysis, the authors used a simplified model of reality, deliberately introducing a small number of classes of land use and a small resolution of data. The research also accounted for two categories of roads. This choice of data is to clarify the functioning of the calculation mechanisms. Sample data also reflects the conditions associated with the irregular borders of the terrain. The choice of the approach was deliberate, as it often occurs in raster analysis. In this case, the way the data is classified is crucial. The assumption in the present analyses is that the raster value reflects the majority of the land use in the vector system (Fig. 2).

For the purposes of analysis, it is assumed that some forms of management of the site are constant, whereas others can be transformed. Hence, in the case of the cells which were assigned housing development, industrial development, infrastructure facilities, forest or water reservoir, there was no calculation of transformation potential. It was assumed that cells that can be transformed are those of agricultural land.

3.1. Neighborhood analysis

The first component of the analysis of transformation potential in spatial development is the neighborhood. Based on the results of research indicating near what classes of land use new

investments are located, a spatial dependence can be defined. Case studies point to residential development often being localized near other, already existing, residential development. Another factor increasing the probability of locating new buildings in a given area is the proximity to wooded areas or reservoirs of water. Proximity to industrial facilities has the opposite effect as it reduces the attractiveness of areas in terms of investments in residential development (KAJDANEK 2011, STASZEWSKA 2013). Various features of the neighborhood will vary between the individual classes of land use. A neighborhood with a negative impact on the investment attractiveness of residential development may be beneficial in the case of office or industrial buildings, e.g. proximity to an airport. An example of calculating transformation potential influenced by neighborhood shows that the final value is equal to the sum of cells and their impact (Fig. 3). In the current example, the presence of housing in the neighborhood increases the total potential (thus the presence of a brown value "+1"). The negative impact results from presence of an industry cell (violet value "-1") and infrastructure cell (grey value "-1") in the neighborhood.

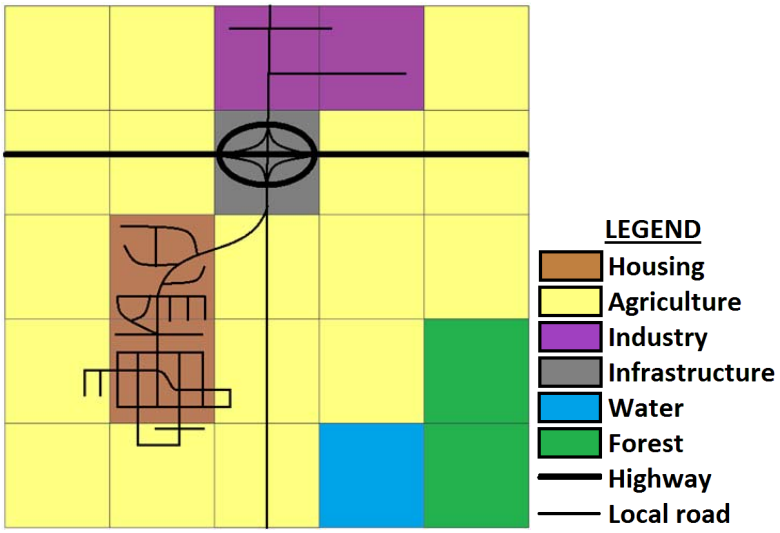

Fig. 2. Sample area. *Source*: own study.

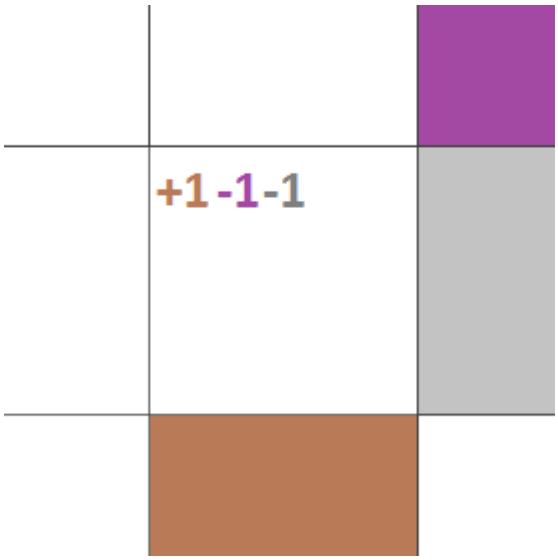

Fig. 3. Example of transformation potential calculations influenced by neighborhood. *Source*: own study.

Below is a graphical representation of an example of the transformation potential of land development for residential purposes (Fig. 4) based on the presence of other classes of land use in the neighborhood represented by different cells.

3.2. Accessibility analysis

As research of other authors shows, spatial development is highly influenced by the accessibility of the potential building site. The presence of transport networks can significantly influence the direction of spatial development. However, not every transport network affects all forms of land use in the same way. The local road network enables the entry to traffic in at any point, thus it will increase the investment attractiveness of the area more effectively than a highway without a point of entry (entrance ramp) running through the site. In such a case, it is assumed that a local road (thin line) increases the transformation potential, while a highway (thick line) has an adverse effect. An area where the highway can be entered directly will be a less attractive place for locating residential development but a better location for a service building. Each transportation network is characterized by a different level of increasing the investment potential of an area and different range of influence. Below, we present an example of the potential of land use based on the existing transport networks for residential buildings (Fig. 5).

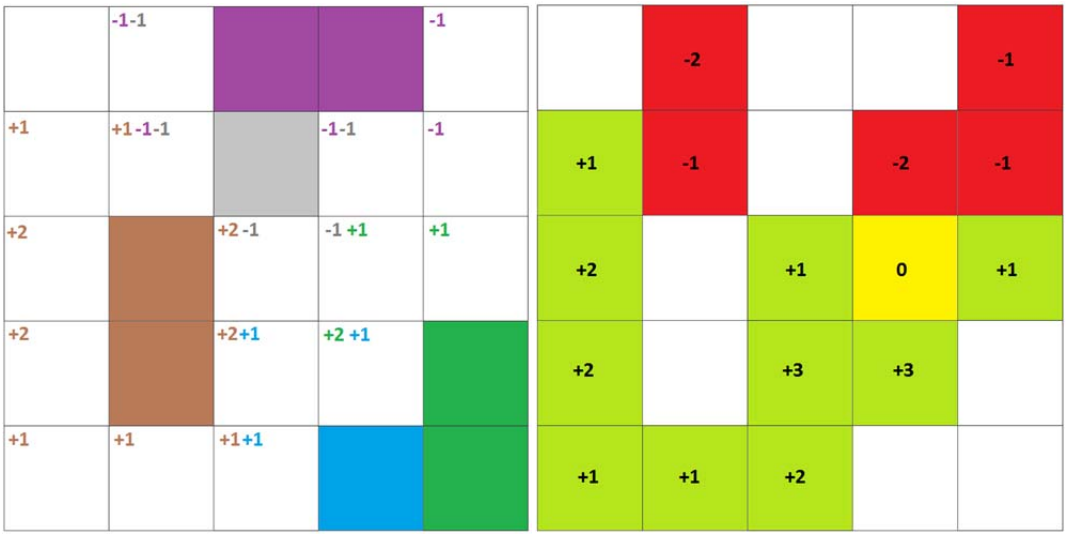

Fig. 4. Land use transformation potential based on neighborhood. *Source*: own study.

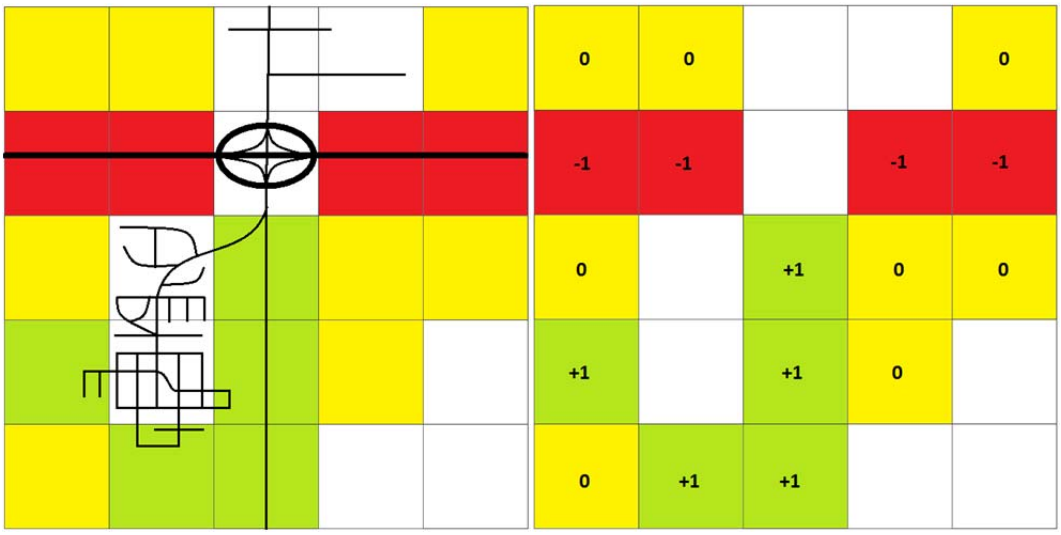

Fig. 5. Land use transformation potential based on accessibility. *Source*: own study.

3.3. Suitability analysis

The final element is the analysis of the suitability of a given area. Not every area is good enough to serve as an appropriate location for new development despite having fulfilled the previously described criteria. Large inclines, wetlands, floodplains or areas at risk of mass movements can reduce the attractiveness of a location in terms of development or event prevent development entirely. One must keep in mind, however, that factors influencing investment potential do not necessarily have to

consist solely of environmental conditions; other variables include variations in real estate prices or different tax rates in the area.

Suitability analysis can be multi-elemental, depending on the available data. For the purposes of graphical presentation, the authors adopted two factors hypothetically differentiating the areas. The first one is economic. The condition is based on the assumption that real estate prices in the administrative boundaries of one area are higher than the other, which increases the transformation potential of one of the zones (Fig. 6). The second feature is information about areas subjected to landslides. In this case, the selected area negatively affects land use transformation (Fig. 7).

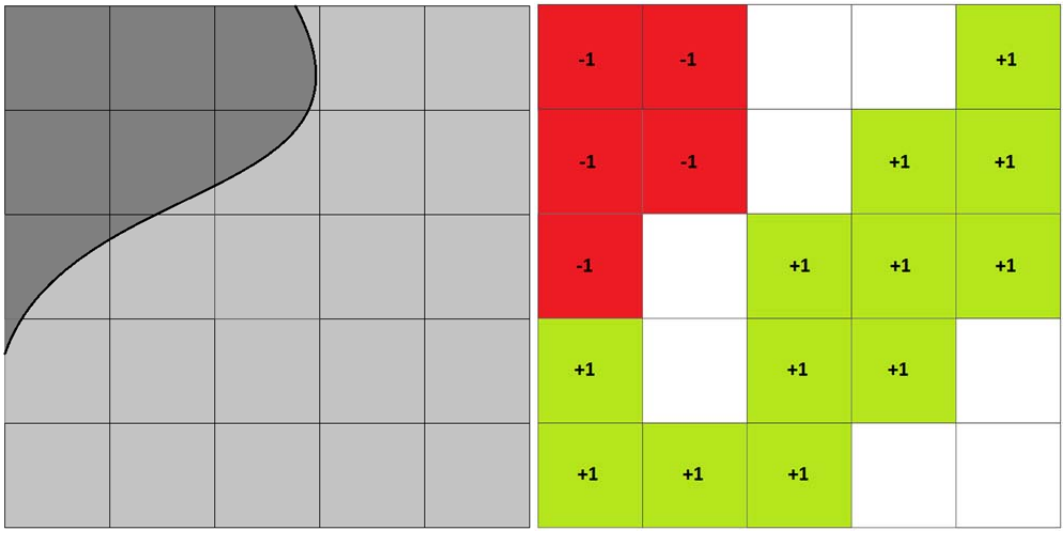

Fig. 6. Land use transformation potential caused by suitability - economic factor. *Source*: own study.

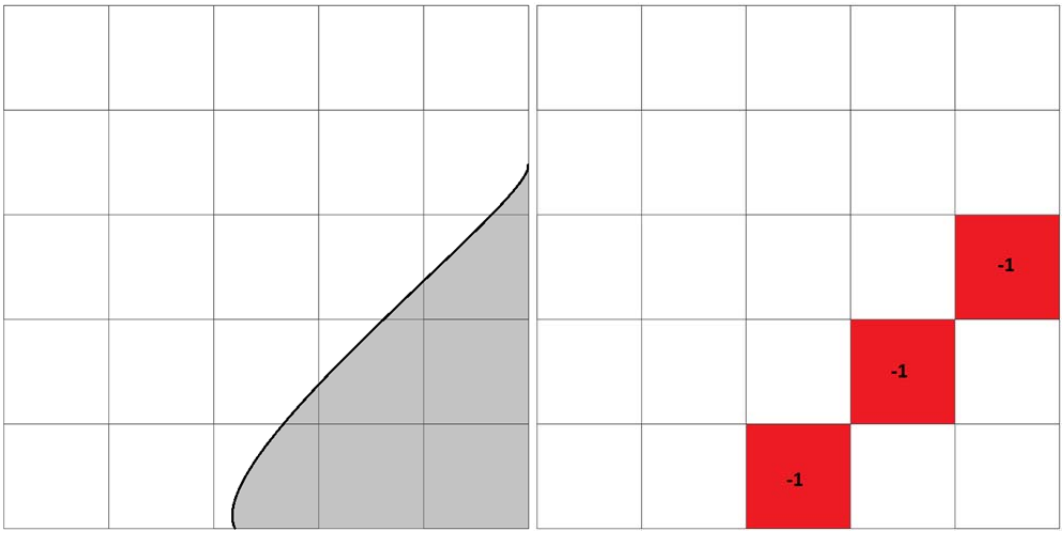

Fig. 7. Land use transformation potential caused by suitability - environmental factor. *Source*: own study.

3.4. Integration of analysis components

Reference squares used in these analyses as cells make it possible to carry out operations on the raster analyses. In this case, each pixel will represent a given cell. This approach can facilitate the process of preparing the necessary data for analysis. The results of various analyses carried out earlier are maps of the transformation potential of the sites for each of the classes of land use. The integration of these elements can be carried out depending on the user's conception. Using raster map algebra, it is therefore possible to obtain the average value of the pixel, the minimum or maximum, or other values that the user is able to define in the form of a mathematical formula based on previously generated maps. In the present study, the overall transformation potential of the site was generated in the form of the sum of the values of the three previous components. As a result of these analyses, it was

possible to obtain a map of the investment potential for residential buildings (Fig. 8).

As knowledge of mechanisms affecting the spatial development of different forms of land use develops, the proposed mechanism of analyzing the transformation potential of a given area can be useful in the rational management of real estate. Knowledge on the probability of the future development of a site can help local governments to reduce unnecessary costs associated with preparing the land for investment and affect the relations between the supply and demand for real estate.

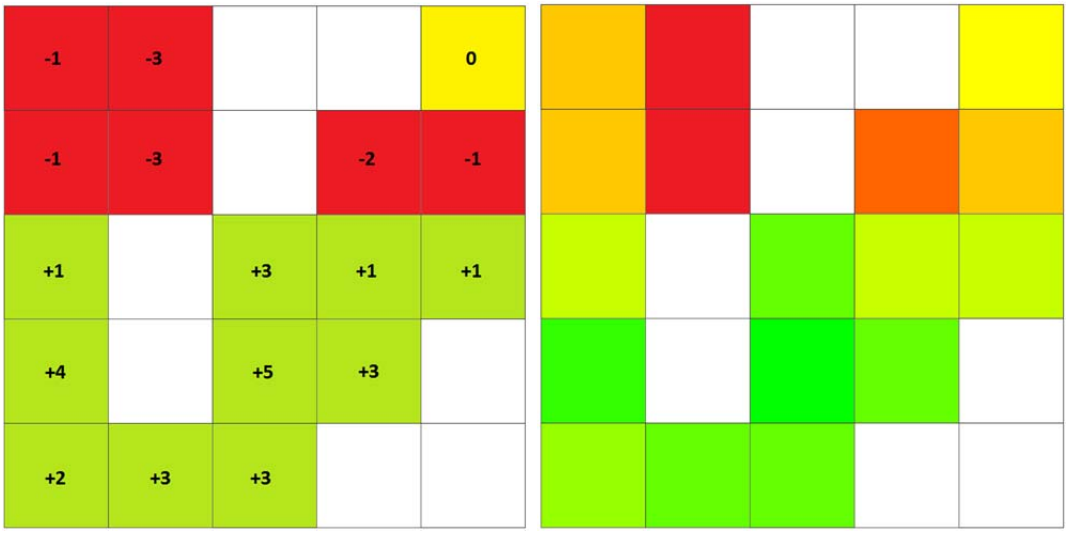

Fig. 8. Total land use transformation potential. *Source*: own study.

4. Summary and conclusions

The excessive designation of development sites in Poland makes it difficult to implement planning decisions in reality. To enable spatial development, local authorities set out significant amounts of land in order to improve their flexibility in the eyes of investors. However, this sometimes involves an additional burden on local budgets, which are already not in the best condition (BOBER et al. 2013). Thus, it seems reasonable to supply local authorities with instruments to help to guide reasonable and realistic spatial policies, so that decisions relating to real estate can support local development.

In order to balance the needs of investors and local governments, the knowledge of land use development potential for various purposes seems to be useful. The proposed model takes into account the factors identified by research in the field of spatial planning. The components refer to such features as: neighborhood, accessibility and suitability. The integration of these components allows one to gain knowledge on the expected overall development potential of the analyzed area. This may help the decision-making process of localizing specific types of developments.

The design of the proposed model is inspired by the MOLAND project (Monitoring Land Use / Cover Dynamics), developed by the Joint Research Centre of the European Commission, and the solutions adopted in the decision support system - Metronamica. However, the principles of the calculations applied in this software do not reflect the purpose intended in this case. One of the reasons is taking into account planning documents as factors affecting land use transformation potential. In this case, the analysis had to be limited in terms of this component, because the results of analyses should present only real mechanisms and trends, not spatial planning documents. Another difference is even the mere fact that this software was created to conduct simulations of future development and includes a random component, which in a sense limits the obtained results. At a similar potential of several cells, it is not necessarily the one whose potential is the highest that is predestined to changes in land use. In these analyses, on the other hand, the mere fact that a given cell exhibits a high transformation potential is considered as desirable information. In the case of the proposed model, the final products of the analyses are not forecasts of future development, but only the potential of cell transformation. Moreover, such a simplified version could also be effective in small-scale planning, while Metronamica deals mainly with research on a regional level or higher.

Although the proposed model is not an ideal solution and is affected by certain factors contributing to the inaccuracy or lack of realism of the obtained results, it seems that making spatial

planning decisions on the basis of such analysis may be more reliable than on those which are currently being undertaken. According to the present analysis, land use transformation potential could serve as a rational direction for further research in the optimization of spatial policies.

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