Method of Potentials for Spatial Planning

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Key words:

1. INTRODUCTION

In this paper we consider different methods of creation of potential surfaces. There is an analysis of advantages and shortcomings of the method of potentials and also a few elaborated models are viewed. We represent the short explanation on how it is possible to calculate world scale potentials of different socio-economic phenomena.

In the middle of the 20th century in order to development of a mathematical method the concept and the model of potential appeared in a geographical science. They are borrowed from physics where they are used for the characteristic of fields of force: gravitational, electric etc. The concept of potential proved to be rather valuable to geography, which keenly required in an objective parameter of interactions (connections) in investigated space. As long ago as 1940-th Baranskij N. N. marked that the distribution of phenomena and interrelations between them made the soul of geography. But various ways of modeling distribution are known to geographers for a long time, whereas the analysis of spatial force connections always stumble on obstacles. It is necessary to stress that even the analysis of separate isolated connections (for example pairs of homogeneous objects) is not so simple. As concerns the interrelation of "all objects with all" few means exist for their revealing and especially quantitative estimation.

Geographical interpretation of phenomena modeled with the help of this method usually includes such concepts as spatial interaction, influence, distribution, gravitation, weight, power, distance, location, availability and so forth. Such variety and an opportunity of multiple-valued interpretation represent strong and simultaneously weak side of the potential method. As a whole, the method was criticized as a version of so-called physicism in the approach to the social and economic phenomena, which have the essence not reduced to physical one.

On the other hand, nobody argued that these phenomena and its distribution on a terrestrial surface at least partly submit to the laws similar to physical one. If, for example, with reference to the population we habitually use such obviously physical categories, as weight or density, why don't use a number of others: a field, potential? Why don't admit, that interaction of settlements creates a field of force that is similar to gravitational and electrostatic fields?

First time such hypothesis has appeared in 1850-th, when Karei G. S. has tried to describe interaction of two cities as function of number of their population and distances between them. But only one century later Stuart J. developed the concept of potential as a measure of a continuous geographical field and used it for research of population and service. In 1941-1947 years he published a number of papers on application of model of potential for the analysis of distribution of the population. Stuart asserted that people in typical or, at least, in the certain circumstances submitted to mathematical rules so that reminded an action of the elementary laws of physics.

The models of potential appeared suitable for the characteristic of the markets, transport gravitations, migrations and so forth. At that period many attempts of its mapping were made. There was even a temptation to use potentials instead of habitual for geography and cartography parameter of density of the phenomenon (displayed by cartograms).

The concept of potential practically penetrated into geography only in 1960-th as the accounting machines capable to carry out the toilful computing works required for calculations at significant number of objects have appeared. However the “quantitative” boom has passed, and for some time the given concept was rarely in use. At the same time it is well known that the science, as well as life, develop cyclically. And nowadays we come back to this method, having taken advantages of a modern level of automation.

We use the potential method in a world scale and try to prove its imposing appearance, in particular, in connection with globalization, aggravation of global problems of mankind, with the growth of attention to irregular development of different countries of the world. Here we represent not only a new demographic potential, but also a number of potentials of other social and economic characteristics in a world scale.

The main goals of the work are to show expediency of application of a potential method for analysis of the new information on distribution of the population, wealth and obstacles (costs, social "illnesses" and so forth) of development, and, simultaneously, to use the method as a way of evident cartographic representation and visualization.

2. SOCIAL GRAVITATION AND ITS POTENTIALS IN A NUMBER OF MODELS AND METHODS OF SOCIO-ECONOMIC GEOGRAPHY

Modeling nowadays is one of the basic methods of modern geography of a society. It implies the research of a structure, functioning, dynamics of the ideal and real social and economic phenomena, objects, systems, interrelations and processes inside them and between them by constructing their conditional models simulating some key qualities of “original”.

Thus, the first substantial assumption is the recognition of presence in social and economic space and its “layers” (geodemographic, geoeconomic, geopolitic) such phenomena and laws which conditionally can be interpreted as gravitational. That they exist, indirectly speaks even the fact of wide introduction in professional lexicon of such terms as force, influence, gravitation, an attraction etc. To tell the truth, we often use them as images, some kind of allegories instead of as strict scientific categories and models. However they, for sure, reflect some essential sides of interaction between classical objects of socio-economic geographers (the countries, areas, cities and agglomerations, industrial centers), being shown in migratory, monetary and commodity flows, in a structure of integrational and military-political blocks and unions, large (transnational) corporations with networks of numerous branches etc.

It is obvious, that the model always conducts to simplifications (in reasonable frameworks), allowing to reveal some main typical features of the phenomenon and, thus, to give new knowledge about it. Formality of constructions and aspiration to use its strengths are peculiar to any modeling. Therefore not the substitution of one method by another, but their mutual addition is expedient in view of strengths of old, traditional and relatively new methods of research. Methods of modeling are laid down in a basis of the given work, being used for construction of digital models of potential and their subsequent cartographic visualization.

Speaking as a whole about application of mathematical methods, it is necessary to note, that for last decades a great number of parameters, indicators, indexes of concentration, centre-graphic methods and measures, concepts of an economic-geographical field, gravitation, form, characteristics of the neighborhood were entered in a geographical science. The given concepts are constructed by analogy to geometrical or physical models. The concept of potential is one of them.

The potential models concern to the group of gravitational models of the geographical phenomena investigating territorial characteristics of structures. Work with this model assumes the calculation of potential surfaces, analysis and mapping of their "relief", revealing various forms of relief and especial nucleus, borders of distribution or potential influence, internal zones, gradients, peripheral areas etc. The concept of potential came in geography from physics as analogy to the formula of gravitation of Newton. More precisely speaking, by virtue of universality of a physical nature (the laws of the mechanics of Newton and the laws of electrostatics of Coulomb are completely isomorphic), the given concept has even closer relation to the first law of electrostatics.

It is well known that the formula of Newton expresses the interaction of two bodies through the product of their weights divided on a squared distance between them. By analogy to the formula of Newton, force of interaction of two settlements (that may be expressed in the exchange of migrants, information, passenger or freight traffics, distribution of diseases) may be written down as follows:

$$I = \frac{P_1 P_2}{D_{1-2}{}^2} \ , \qquad (1)$$

where P_1 and P_2 - population of the settlements and D_{1-2} - distance between them. Thus, the potential of interaction (${}_jV_i$) of any point of territory (j) with all settlements (i) will be expressed as follows:

$${}_jV_i = \sum_{i=1}^{n} \frac{P_i}{D_{ij}} \ . \qquad (2)$$

Calculating demographic potential not for all points of territory, but only for settlements, it is possible to use the formula:

$${}_jV_i = \sum_{i=1}^{n-1} \frac{P_i}{D_{ij}} + P_j \ . \qquad (3)$$

After such, not accurate, transformation the analogy of settlements to physical objects becomes a relative one. The problem is not only in this concrete assumption. It is necessary to admit that the whole “social physics” was criticized for oversimplification. The reason is that the population, resources, manufacture etc. are not weights and not electric charges, and physical (geophysical) distances in social and economic interactions are also "deformed" by the time, cost of moving, different sort of political, tariff and other barriers all which concrete variety usually is very difficult to take into account. Nevertheless, the general principles of interaction in gravitational and electric fields (they are stronger, when their “agents” are more powerful and when they are closer each other), most likely, operate also in geosocial fields.

This circumstance or assumption (some simplification is necessary for any modeling) helps geographers to receive interesting decisions and conclusions. You see the assumption that the force of interaction of settlements is directly proportional to their size and is inversely proportional to distance between them, does not contradict our intuitive representations and it is partly confirmed empirically. It is remarkable, that the exponent in the gravitational formula (1) among various researchers varied from 0.5 up to 3.5 and “on the average”, as well as in a lot of concrete cases, was close to 2.

It is important to note the fact, that calculations of potential are especially cartographic. Maps in this sphere practically have no statistical analogues (tables, lists). More precisely speaking, such analogues have no sense as results of work are deprived of presentation, and with it the opportunities to reveal visible images, forms of statistical “relief”.

The calculation of potential according the formula (3) with usage of all settlements of investigated territory became at the first time the most widespread, almost traditional method. At the same time the other updatings of calculation of potential exist and may be useful to the purposes of the applied analysis. In some researches the design procedure of potential is stated not on settlements, but on countries, areas, other administrative or statistical units. The population of such cells in these cases conditionally concerns to their administrative, modal (largest) or geographical centre. To check up this assumption different maps were designed on both methods. Their comparison resulted in the conclusion, that “reliefs” appeared rather similar.

A number of consequences are received if we use formula (3) for calculation of potential where the total potential is submitted as the sum of the self-potential equal to weight (for example, population) of a point and the external induced potential, that is a measure of position produced by external for the given point forces (settlements). For large settlements it results in sharp increase of value of potential only due to their own weight. In connection with this there are offers to calculate potentials for settlements without taking into account their own population.

It is important to note, that at calculation of potentials as parameter P (formula 3) may be used not only population of points (it is the most traditional example), but also certain other parameter. It is necessary, that it conditionally could be compared to weight or a charge (amount of electricity) in its interaction with other objects. It is possible to apply different methods also when we take into account the distances. Usually they take the direct ("air") distances calculated as increments of coordinates. Sometimes such simplification is inappropriate, because there are no basic obstacles that can not allow to take into account the real length of ways, time or money spent on overcoming of the way etc. The mentioned factors are especially important for those areas where the roads connecting settlements, enterprises etc. have a difficult configuration (for example, because of complexity of a relief and other environment). However, it is necessary to admit, that the calculation of potential in view of a real network of roads is extremely labour-consuming.

For this purpose the method using electric modeling on grids of resistors may be offered. So, between the formula of influence of any point i on any point j:

$$_jV_i = \frac{P_i}{D_{ij}} \tag{4}$$

and the law of the Ohm:

$$I = \frac{U}{R} \tag{5}$$

it is simple to establish analogy that allows to apply electric analog circuits to construct maps of potential of different parameters. So, the network of roads is modeled by a set of resistors, the size of resistance (R) is proportional to the length of ways, their throughput, speed of movement along them, time spent in a way etc. On the constructed model the electric voltage (U), proportional to the weight of points (P), is put serially to points i. And in the point j values of force of a current (I) are measured, then they are summarized and give final value of potential. This operation is repeated for each point.

At the same time, it is obvious, that the degree of detailing of calculations should correspond to the width or narrowness of the content of the research, spatial scale and degree of generalization of constructions. So, for example, it is not meaningful to specify and concretize parameter of distance, bringing it under the rigid transport circuit if the task is to work out the general demographic or manufacturing potential on extensive space where for different kinds of interaction (streams) different route networks and types of transport can be used.

Discussing different methods of elaboration of potential models, it is necessary to pay attention to the fact, that the full potential, which value includes self-potential of "meaning points", is often used as a model for revealing forms and structures of the geographical phenomena. But, it automatically, due to the account of interposition of weights of objects (the induced component) and its continuity, generalizes these forms and structures. Such automatism makes it less dependent from a configuration and even density of an initial network of points or cells used in calculations. The given property is especially appreciable in comparison with those more traditional models, for example, cartograms of population density, which operate with discrete sites and do not take into account their interposition, and generalization is reduced to arithmetic averaging of parameters in frameworks of more and more extensive cells (the countries instead of its regions, continents instead of the countries etc.).

3. CALCULATIONS OF WORLD SCALE POTENTIALS

In our case, as it is usually done, the presentation begins with calculation of demographic potential. Then on its basis the calculations of potentials of other phenomena and regional fragments of the world are conducted. Generally for the whole Globe such computations have no reflections in the accessible literature (if they have ever been undertaken). Meanwhile, this scale has specificity and complexities that are necessary to take into account.

Utilizing a great number of points (for calculations at a world scale the basis consist of about more than 20 thousand settlements) the own population of settlement adds in value of potential rather small share in comparison with its basic part represented by total induced potential of the other points. The exception, undoubtedly, is the value of potential nearby very large cities.

At calculation of potentials for separate regions the question of a choice of territorial frameworks of external forces (agents of influence) is very important, and their boundaries, as the common rule, are not limited to territory of mapping of potential surface. The points included in calculation may or even should be situated far beyond the mapped site. It is obvious, that this choice is caused by the purpose, for which the potential is calculated and mapped. So, the maps of demographic potential of small area, but designed in view of influence of all country, continent or the whole world, have valuable property: they are comparable for different such areas as in all cases the aggregate number of the external population included in calculation is identical. Otherwise each map has its own system of readout of potential. Applying method of potentials to various on scales but overlapped territories, it is possible to allocate their own potential and influence of near and distant neighbors.

This external influence is displayed by the induced potential. It is frequently interpreted as a measure of potential of the unequal geographical position of territory, and the word “potential” itself gets in this case the additional sense connected to representation about geoposition as a potential source, a resource of development.

Technically the surface of induced potential can be achieved if to calculate potential using the standard method, but the weight of all points of considered territory to equate to zero, receiving for them values of potential only induced from behind its limits. The same result can be achieved, if from the full statistical surface of potential (the territory itself and adjoining territories) to subtract the surface formed by points of the considered region itself.
The calculations of the induced potentials (especially at the big number of considered points) are more convenient to make not in the points of the concrete network, but in tops of any correct geometrical network, for example, network of squares put on the map. Just this method is used in the given work. There are a number of arguments (Tikunov, 1997 etc) proving that such method is even more correct at calculation of potential for any point of territory.

Calculation of potential on a regular network leads to the results close to those received with the help of other methods, however the time of made calculations reduces. The reason is the calculation of distances not from each point to any other, but from points to units of the network. The most essential difference in case of calculations on regular lattice is the fact that large settlements are not allocated so boldly on the average background of potential surface, as in the case when we use the traditional technique. At the calculation of the induced potentials, both on a regular lattice and on the basis of the real network of points, distinctions of the corresponding maps appear even more insignificant.

At calculation of potential surfaces with the usage of correct geometrical networks it is possible to occur that the unit of a network will be situated very close or even exact on a place of settlement. In this case, when the distance between the unit of the network and settlement is equal to zero, calculation under the formula (2) used for such calculations, results in uncertainty (to infinity in a relief). The formula (3), when at the calculation of potentials this obstacle is overcome by not very reliable addition to value of potential the weight of the point for which this calculation is carried out, is also not quite perfect. For the decision of this problem, for example, Frolov (Frolov, 1975) offered the design procedure eliminating formality of reference of all population of settlements to their centers by approximation of settlements not by points, but by equal to them circles with in regular intervals distributed population density.

In this paper a little bit other way was applied (the formula (6)), but as a matter of fact it is rather close to the logic of abovementioned variant:

$$ {}_jV_i = \sum_{i=1}^{n-1} W(d_{ij})P_i \ , \qquad (6) $$

where $W(d) = 3/2 - 1/2d^2, d \le 1$
$W(d) = 1/d, d > 1$

The grid of cities with the population more than 10-20 thousand inhabitants (more than 20 thousand settlements in total) is utilized as a basis of settlements. The data on population of the cities were taken from the site http://www.gazetteer.de. It is necessary to note, that the received grid can be hardly considered homogeneous, because for a number of the small (I mean their population) countries the settlements with the population more than one thousand persons were taken into account whereas for such large countries as China or India the qualification of minimal population was up to standard of 25-30 thousand. However in the world scale the abovementioned distinctions hardly played an essential role, especially if to take into account the fact that in result we used the total population of the countries and not just that its part which fell to the mentioned points (about it we shall tell later).

For better automatic calculations (as it has been already spoken above, the usage of the given method doesn't result in losses of the information) the regular network, which units were all crossings of parallels and meridians with the step in 1 degree, was taken.

It is necessary to note that the total population of the countries was taken into account in the potential models. The agricultural population, which for the world on the average is about

50%, was included in considered models under the simplified circuit. The agricultural population was distributed in accordance with its share in each separately taken country and added to the population of the settlements (that we use as basic points) proportionally to their size. Thus, it is possible to speak about the population living in the settlements bigger than 10-20 thousand persons and about all the rests, which geographical variations are taken into account at the level of the whole countries and in their borders repeat distribution of the population living in the settlements of the specified size.

In protection of this method it is possible to adduce the statements of Stuart, the founder of method of potential. In 1947, proving application of this method, he referred to four empirically deduced rules. First of them is known as a rule “the rank - the size” (this rule connects the number of population in any city with its rank in the system of distribution of settlements and with the size of the largest city). According to the second rule confirmed on the example of the USA, the number of the cities with the population less than 10 thousand persons practically corresponds to the share of the population living in the given group. In the third rule it is confirmed that the distribution of the population over the territory may be described through demographic potential in a number of points like the same as the magnetic potential is described in physics. The fourth rule establishes the close interaction between demographic potential and density of agricultural population.

Thus, consideration of various methods of creation of potential surfaces allows exposing the following basic conclusions and assumptions, adhering which it is possible to carry out correct calculations, in particular in a global scale:

- There is an opportunity of calculation of potential surface on the basis of geographically selective statistics (only the cities of the definite size) that reduces the volume of computing works. Generally, it is necessary to use this opportunity very cautiously, not overcoming some limits. For more accurate calculations on the limited territory in large cartographic scale sometimes it is necessary to use all settlements. However such method may hardly deform the planetary picture.
- Calculation of potential on the regular network of reference points is quite well-founded methodically, because emphasizes the continuity of the potential surface, suits better for automated interpolation of isopleths etc. This method has the shortcoming inherent to all methods using regular networks for calculation. I mean complexity in the choice of the optimum size of the network and ambiguity of the decision, its dependence on how this network to arrange on the map. But at practical calculations of potential the divergences may be absorbed due to intervals of the scale of isopleths and make no influence at the final result.

4. EXAMPLES OF WORLD SCALE POTENTIALS

As it was already mentioned, the creation of potential surfaces is possible on the basis of various social and economic characteristics. However it is necessary not to forget one limiting condition (according to the approach used in the concrete work): it is necessary that the parameters have close relation to the population as its differentiation is incorporated in the basis of the model. If to break the mentioned principle, the potential surface within the framework of each separate country will lose any sense, though the global structure will be basically realistic. All taken parameters do for the mentioned rule – population for two dates (1950 and 2000), average annual rate of change of population, GNP per capita, estimated number of people living with AIDS.

For the demographic potential, which was designed for two dates (1950 and 2000), we used the abovementioned method. Calculating other models, the surface of demographic potential, which values in each settlement of the basic network were taken, was increased on an average national value of considered parameter for any separate country. By this simple operation the world potentials of other characteristics were obtained, though inside any separate country, even in extensive one, its variation was relative and simply repeated the differentiation of the population.

Fig. 1: Demographic potential, 1950.

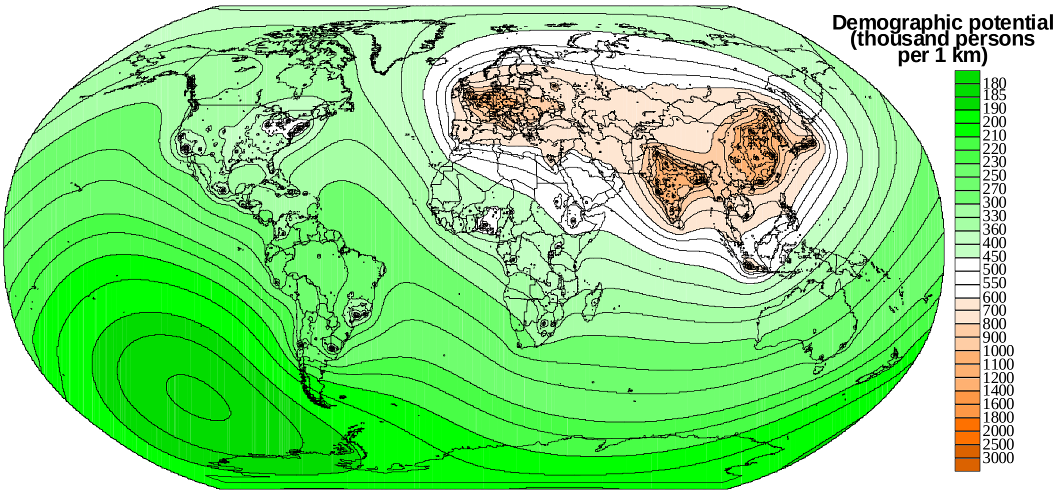


Fig. 2: Demographic potential, 2000.

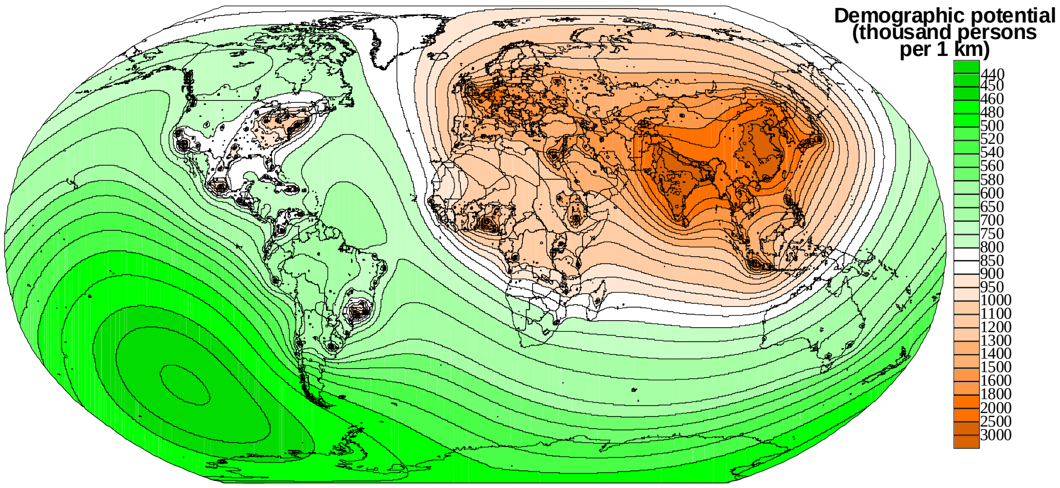


Fig. 3: GNP potential, 2000

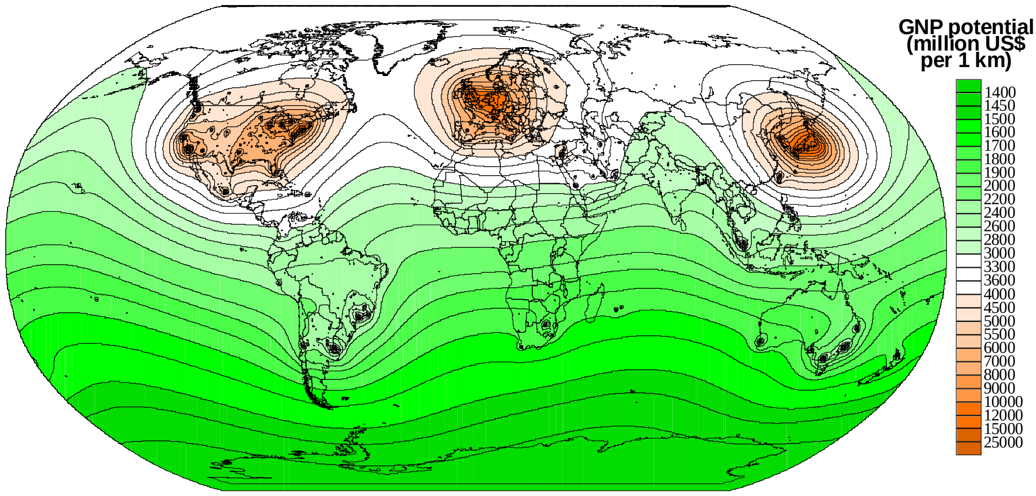


Fig. 4: Population growth potential, 2000

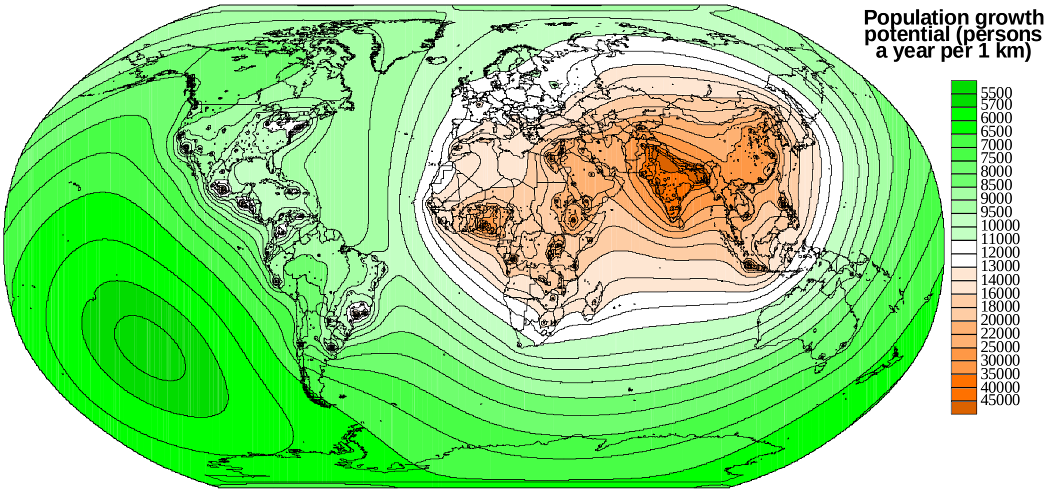
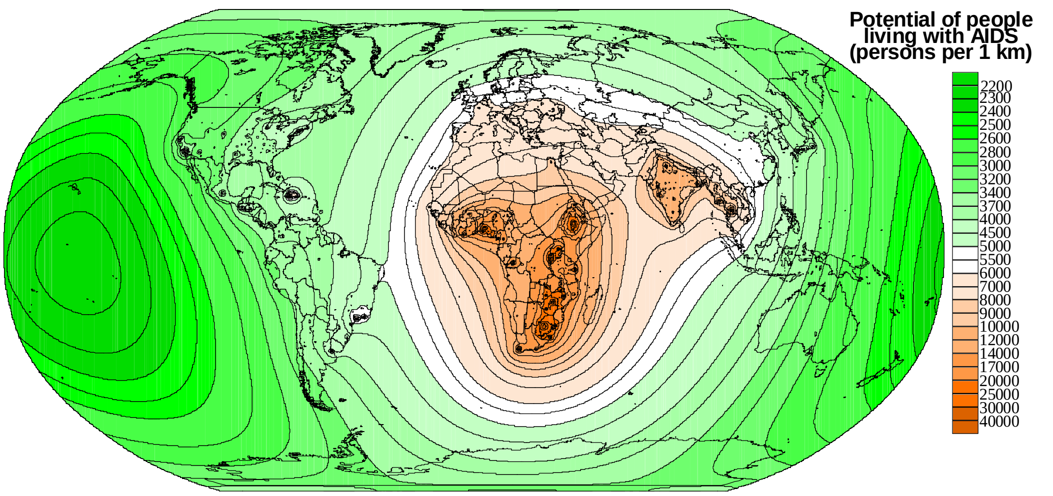


Fig. 5: *Potential of people living with AIDS, 2000*



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