

TECHNIQUE FOR CONSTRUCTING CONTINUOUS METEOROLOGICAL FIELDS FROM POINT MEASUREMENTS USING INCORPORATED EFFECTS OF TOPOGRAPHY

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ABSTRACT

This paper analyses the possibility of applying Geographical Information System (GIS) to climate research. It presents a method based on assumption that if there are similar topographic conditions, it might be suggested that there are also similar climatologic conditions in the indicated area. The second principle is a kind of meteorological uniformitarianism. If there were similar climatic conditions in the historical period in the certain area we can assume with high probability that in this area there are still similar climatologic conditions. The condition is that the topographic situation must stay the same. Due to that fact, in present conditions, we can transfer information on the basis of fewer number of indicating points. On the basis of this guidelines, the digital maps of climatologic conditions can be built. This is a proposition for these meteorological data fields that need to be constructed from point measurements and from spatialisation of obtained values from the whole examined area. The major aim of this paper is to present GIS as a useful tool for data verification, analysis and the presentation of climatic parameters over medium scale areas and a relatively long period of time.

KEY WORDS: Cartographic modelling, climate, GIS, probability

INTRODUCTION

Methodology of climatic base utilization in national geographic information systems and linking them with topographic bases is still under development. Such elements as soil structure, geological and morphological forms and parameters of climate are very important for right management of Earth's goods (Lee et al., 1993). As a source of all mentioned above data, with the exception of climatologic ones, specially processed and up-to-date materials, both cartographic and remote-sensing, can be used: maps, photos, pictures, thermals registrations. Some of climatologic data are of different nature and are being gathered in listed form. Especially precipitation, air pollution etc. measured in point. The elaborations of climate elements' distribution in medium scales mainly in the areas with not sufficient number of measurement stations are still being discussed and examined. Attempts of such elaborations are in (COST 719, 2004). Accessible sources of data represent different levels of reliability with regard to their spatio-temporal representativeness. The probability to indicate correctly the average value of parameter depends on the conditions and time of measurement. The reliability of climatic parameters connected with adopting adequately long measuring periods, their representation level, variation range

and time step were additionally marked for the values in measurement stations. In this way, users can state how much the given values are reliable for their aims.

The reliability of parameters depends mainly on the representativeness of data concerning the character of changeability of phenomenon. Those parameters characterize constant environmental phenomena and their reliability is obtained derivatively from the models of their values' distribution.

Constant phenomena qualified on the basis of insufficient number of indicating points are particularly subject to diversified outcomes. The precipitation was an example on which different trials to obtain constant information on the basis of phenomenon's model constructed from the point data were tested. Mainly the average values obtained during many years are used for modelling climatic conditions. Nowadays, to create model of climate elements, all available data of different levels of reliability are used. Because of that fact, information obtained from the model is always going to include uncertainty either because of mistakes in data on which the analysis is based or imperfection of their transformation procedures.

When the measurement points are not representative enough to establish phenomenon's distribution (too sparse measurement net, not representative location of measurement points, incomplete measurement period), it may happen that there will be parameters' values, between the indicating points in reality, that would be impossible to estimate on the basis of geostatistical analysis. In such cases, at least five ways of modelling can be used. They may be based on: indicating terrains for which information is not certain, finding environmental and historical analogies, diminishing the elaboration's scale and introducing additional topographic parameters which will help to introduce phenomenon's distribution into the model.

DIVISION OF EXAMINED AREA INTO TWO KINDS, THE ONE WITH INFORMATION ABOUT GREAT DEGREE OF PROBABILITY AND THE ONE WITHOUT INFORMATION

The first kind of areas are the ones in which complete, reliable and up-to-date information can be obtained. The rest can be described as "terra incognita" of information. These can be described, as other similar areas, with signature "lack of data".

The following ways to indicate values on the basis of point observations are proposed: Voronoi's mosaic on the basis of Thiessen's polygons (Thiessen, 1911; Boots, 1987) which are created in the process of linking individual perpendicular bisection of Delaunay's triangulation (possible deformations in picture of this condition come from their afinical deformation). Boundaries established in such a way depend only on surface distribution of measurement stations. Initial evaluation of values' distribution can be done while observing changeability of the phenomenon with the help of blockdiagram (fig.1). In this way, the differences between values in individual basic fields can be observed. By analysing places with huge differences between values in the edges of the fields, one can determine areas in which a special attention should be paid to the way of indicating mean values between indicating points or exclude particular areas as "lack of data". In this and in the next paragraph, example models are shown together with detailed elaboration of this issue (Bac-Bronowicz, Borkowski, 2003).

A trial to establish huge differences on the basis of correlations between scalar field of precipitation and changeability of sculpture of the earth's surface is another way of determining areas of uncertain information about precipitation. To achieve this, the scalar fields of precipitation were approximated using the spline functions of minimal curvature. (thin plate spline, Aronov 1990).

Standardised difference field of this possibility is shown in fig.2. Also in this method of indicating basic field it is visible that the height of the station cannot be omitted in the process of modelling.

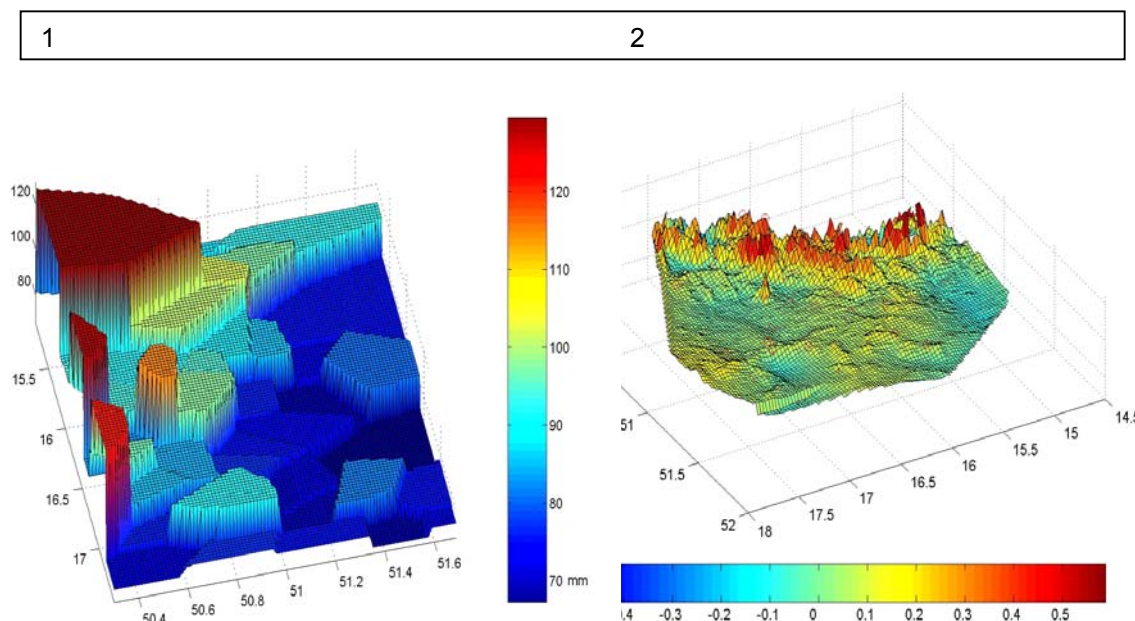


Fig. 1. Blockdiagram of average sum of precipitation. May and July (1971-1980)

Fig. 2. Standardized reference unit of sums of precipitation in vegetation period (1971-2001) and DTM. Approximation using spline functions.

FINDING ANALOGIES OF VALUES' DISTRIBUTION OF PHENOMENA IN OTHER HISTORICAL MEASUREMENT PERIODS

The construction of precipitation model on the basis of historical data may increase reliability of information. This conclusion seems to be pertinent especially when we interpolate model from the existing data, using linear interpolation between distanced monitored stations.

When a station does not exist, there is a need to put some information about the determined probability of the climatic conditions analogy – which denotes in what way the next unit would be similar and whether the information could be removed. It would be a kind of meteorological uniformitarianism – the theory that meteorological phenomenon may be explained as a result of existing forces operating in the past (Fundamentals of physical geography, 2004). The theory suggested that continuing uniformity of existing processes were responsible for the present and past

conditions of our Earth. In 18th century, uniformitarianism suggested that the continuing uniformity of existing processes should be used as the framework for understanding the geomorphic and geologic history of the Earth. Today, most theories of landscape evolution use the concept of uniformitarianism to describe how the various landforms of the Earth came to existence.

The proposal of dividing the area around the station into the regions of homogenous climatic conditions containing the same type of information is the next step towards adding information about the distribution of phenomenon considered to be constant and distinguished on the basis of point measurements. Such a solution will be tested along with developing a Lower Silesia Spatial Information System in Department of Geodesy and Cartography of the Office of the Marshal of Lower Silesian Voivodship (Bac-Bronowicz, Cieśliński 2004).

The value of precipitation in twelve measurement periods was always a feature describing analyzed field in historical periods. While indicating the range of multi variant field, the areas similar in respect to precipitation value in chosen measurement periods were indicated, establishing its changeability range in individual classes. Increasing reliability of information obtained from atmospheric precipitation's distribution on the basis of analogy of its distribution in the period 1889-1930 was proposed. There were over 400 measurement stations in Lower Silesia during the pre-war period. Nowadays, there are approximately 50. On the basis of great number of stations, regions with similar average precipitation value distribution in the periods of great importance for agriculture in historical period were indicated. On the basis of this, the borders of sub-regions were established. It was supposed, that if in the historical period, the precipitation distribution was similar in a sub region, and the natural conditions have not changed, so, in consequence, the values of precipitation parameter measured nowadays in fewer measurement points can be accepted (on the condition that they are still similar when it comes to parameters' distribution). On the home page of the author (<http://www.geo.ar.wroc.pl/gislab.html>) one can get to know in details the system of availability of historical information about the precipitation in Lower Silesia

The division of Lower Silesia, on the basis of historical and present stations, into areas of similar parameters of precipitation obtained from cluster analysis is shown in Figure 3.

COMBINED MODELLING OF PRECIPITATION VALUE IN GIS – NOT ONLY ON THE BASIS OF VALUES IN POINTS BUT ALSO ON THE BASIS OF ADDITIONAL PARAMETERS' VALUES.

Various spatial phenomena distributions should be elaborated with the help of, so called, phenomena explaining distribution of other phenomena. The maps constructed using the methods of incorporating topography effect were found to be better in spatial distribution of precipitation in lowland and upland part of Lower Silesia region (Poland). Cartographic modelling mentioned above was elaborated in research project "Geographic Information System tools in modelling of climatic data in regional and local standard " no. 8T12E04221 financed by The State Committee for Scientific Research in Poland. Selection of the reference unit, which is accommodated to the needs, detailing level and accuracy of the compilation scale is a very important point of the construction of the spatial information system for the climate. After the analyses for elaboration of parameters' distribution, the basic fields in elaborations of the size of 1 km square were chosen. In Poland one of the basic systems is the TEMKART (Podlacha, 1999). The initial unit is a trapezium with sides that correspond with one degree in geographic reference system, divided into fields with sides 10' and 5'. Then the field is

divided into 9 rows and 12 columns. In elaborated area units are about 1 km square and fluctuate between 0,981 and 1,022 km square. Further division is possible using quadruple system.

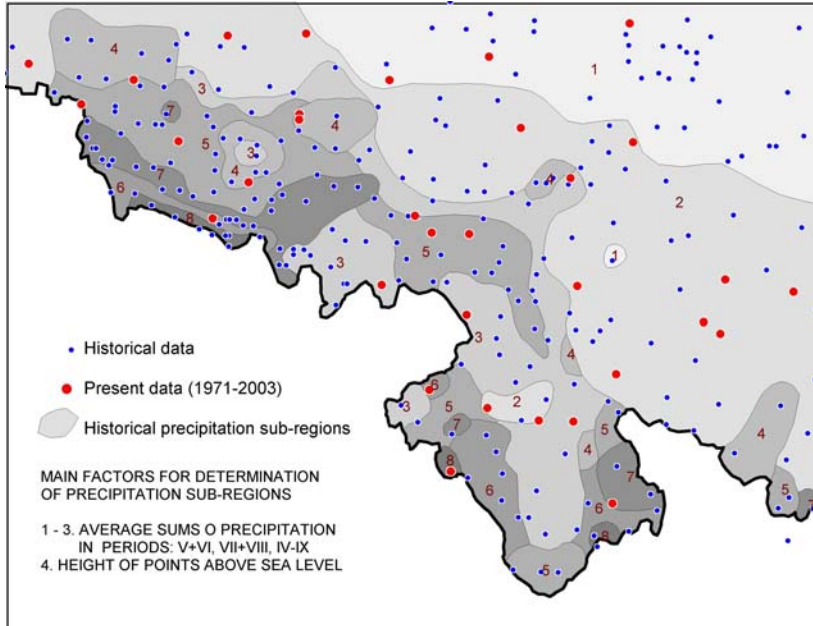


Fig. 3. Similar climatic conditions in the historical period in the certain area suggest similar present climatologic conditions

Moreover, the places of measurement are not representative enough for the whole area. When a measurement station does not exist in elementary field, there is a need to put some information about the determined probability of the climatic

conditions analogy – which denotes in what way the next unit would be similar and whether the information could be removed. The demand for accuracy resulted in efforts to incorporate the effects of topography. In this proposition, elevation data are applied. The surroundings of measurement stations were established taking into account the influence of topographic elements on the borders of area with similar value of indicated parameter. To obtain that, the types of land cover were distinguished and the terrains surrounding measurement points were set taking into consideration the similarity to the measurement area. The acceptable difference in elevations in measurement points' surroundings was established.

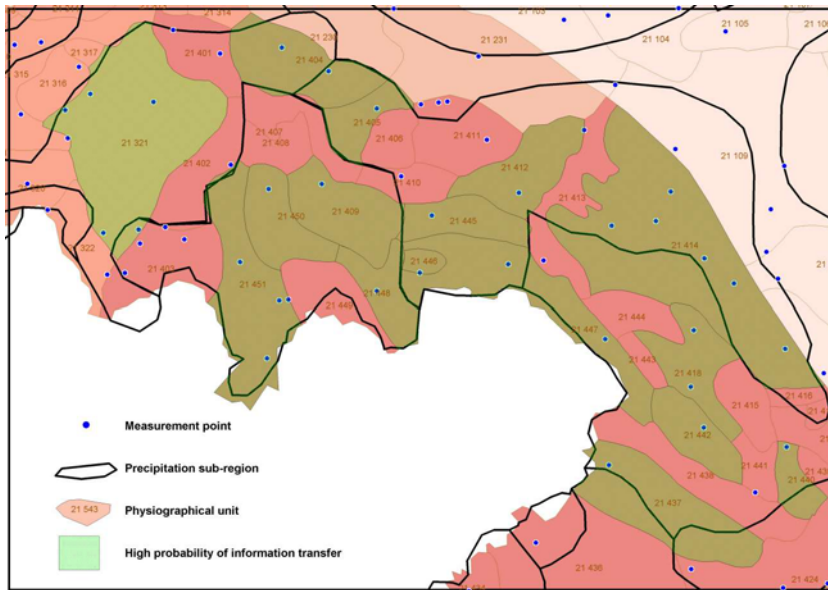
PHYSIOGEOGRAPHIC UNITS

For correct determination of climatic phenomena distribution the author, as one of the variants, proposes the application of physiogeographic units by Kondracki with borders coming from the shape and morphology of terrain.

Those limited units take into consideration such elements as: relief, slope, exposition, altitude, geomorphologic structure, etc. Dense network of measuring stations is required especially in the mountains and hills, because of a very strong influence of the relief. Also localisation on the northern or southern slope influences measured parameters.

The best solution seems to place a station in each unit previously separated by different topographic conditions, as well as to make the data representative for the whole area. Existing network does not meet those conditions in Poland. In studies of climate we have to focus on the existing data.

Using the Kondracki unites (Kondracki, 2000) it is possible to distinguish morphological barriers, which are the main factor of climatic characteristics' distribution. A number of features have got a



meaningful impact on the distribution of climatic characteristics, and they influence also the placement of borders of physiogeographic units. Adopting those units as basic ones in climatic modelling raises the reliability of the received results.

Fig 4. Assigning point information about adequate attributes

SIMILAR GROUP OF ACCOMPANYING AND AFFECTING THE PHENOMENON DISTRIBUTION FACTORS

In similar way we can differentiate areas which have similar group of accompanying and affecting the phenomenon distribution factors, for instance, for temperature distribution, the units which are typical of this area's values above the sea and southern or northern slopes. The map produced with methods incorporating topography effects were found to reflect better large and small scale variations in spatial distribution of climatic parameters (Bihari, 2000; Pardo-Iguzquiza, 1998).

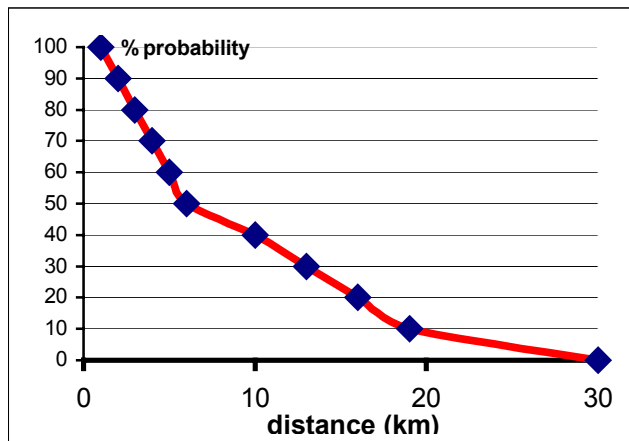
For Lower Silesia, the trials to include into the model the value of parameters of different topographic elements were conducted. Those elements were: height above the sea level, land cover, wind direction or slopes, considered, in literature, influential on precipitation distribution. It is possible only if the influence of those additional factors on the phenomenon's distribution was determined.

What is proposed is the division of the area around the station into the regions of homogenous climatic conditions containing the same type of information. Geometric basic units of the system can be aggregated in adequate areas on the grounds of their affiliation to certain climatic regions. Each region consists of elementary fields of climatic groundwork, which will be assigned to determine the type of climatic conditions with certain degree of climatic risk which is the product of probabilities of information transfer.

Assigning the probabilities to areas, according to the distance from the measurement point.

Each field surrounding the station was assigned the value of probability of precipitation sum of the same value as in the measurement point around which we create surroundings. Fields which include meteorological station (that means the closest surroundings) can be considered fields with certain information, where the probability is 1. While increasing the distance between surroundings and the measurement points, the reliability decreases.

Basing on the model of probability's distribution together with the increase in distance between meteorological stations, it was assumed that probability of the transfer of the values of precipitation sums diminishes together with the distance Fig.5.



Surroundings where probability of information transfer was over 60% were assumed to be reliable. Up to the fifth surroundings the probability changes in a linear way.

For the rest, additional information should be considered.

Fig.5 Distribution of probability of information transfer on the basis of distance between surroundings and the measurement point

Assigning to the surroundings the probability, according to the similarity between heights above the sea level

Apart from the distance from the measurement point, also the height of measurement point's surroundings was taken into account. For each surroundings, the probability of the same precipitation sum as in the measurement point according to the difference of height between the surrounding's field and the height of meteorological station was established (Fig.6). The probability of information transfer was preserved as in the previous paragraph. The height of the station above the sea level and the class of probability of transferring information were analyzed.

On the basis of assumed probabilities of transferring information, each basic field was assigned information about the probability of transferring value of precipitation parameter from the nearest measurement station. Some fields obtained information that it is not possible to interpolate the closest value.

The condition of surface continuance in surroundings was preserved while defining probability of height. This condition excluded transferring information in mountainous terrains in the area of 3km, or even less, around the station. 2 groups of height were distinguished (400m above the sea level was the limit) and acceptable differences of height for the field with measurement station were classified (fig. 6). In this example, influence of distance and differences between heights on diminishing of probability of transferring information were treated equally.

In the same way, the modification, which assumes giving different importance to the factors accompanying distribution, can be introduced. For example, the significance of probability for similarity connected with height can be diminished. Other information can be added as well while establishing probability of transferring information. In the case of climatic data this will be slopes in terrain and exposition.

Similarity, which allows to transfer information to the surroundings of measurement point, can be determined on the basis of land cover. Nowadays, the attempts of indicating terrains around the measurement stations of similar land cover, due to its influence on similarity of climatic conditions, are conducted in the project. Data used in the research are established on the basis of joined classes of land cover from CORINE 2004.

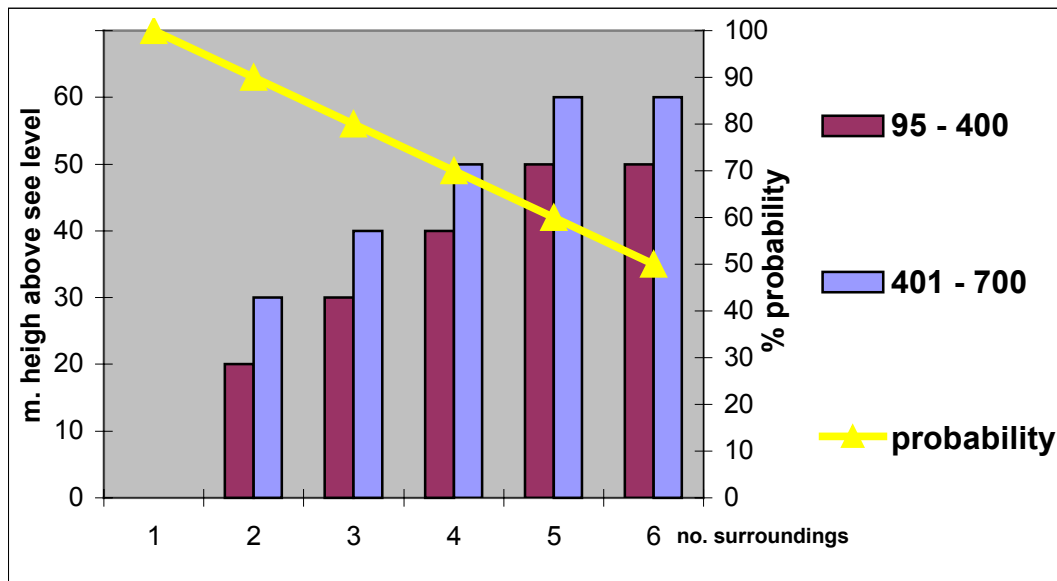


Fig 6. *Acceptable difference of height above sea level*

CONCLUSION

The reliability of the model of phenomena parameters' distribution established on the basis of measurements in points is the one that was obtained for the least reliable parameter put into the model's creation. It concerns both: the localization of the measurement's place and parameter's value. Subjective experience of an author may have influence on the modeling on the basis of insufficient number of points. Lack of knowledge on that fact may lead to drawing wrong conclusions when it comes to phenomenon distribution and to elaborating incorrect forecasts. Describing probability of information transfer while creating a model on the basis of insufficient number of points may increase

the reliability of that model. Indicating fields of alternative neighborhood (2 or 3 indicating points) allows to indicate zones which need to be paid special attention to when interpolating from model. Complementary research is advisable in those zones. In Fig.7 only three surroundings are shown. Next ones are determined in the same way.

Sometimes it is not possible to transfer information from some places because there are different natural conditions or different time of observation than in the places from the nearest neighborhoods. It seems that it would be better to leave some areas as terra incognita than to create false model of monitored phenomenon. These places are presently characterised with lack of data. Such a way of interpreting information from phenomenon's model indicates areas which need additional researching before making a decision conditioned by examined parameter's distribution. The above mentioned method of spatial interpretation of phenomena measured in points can be also used when monitoring parameters indicated in elaborations for the needs of environment protection, geology, soil science, hydrology etc.

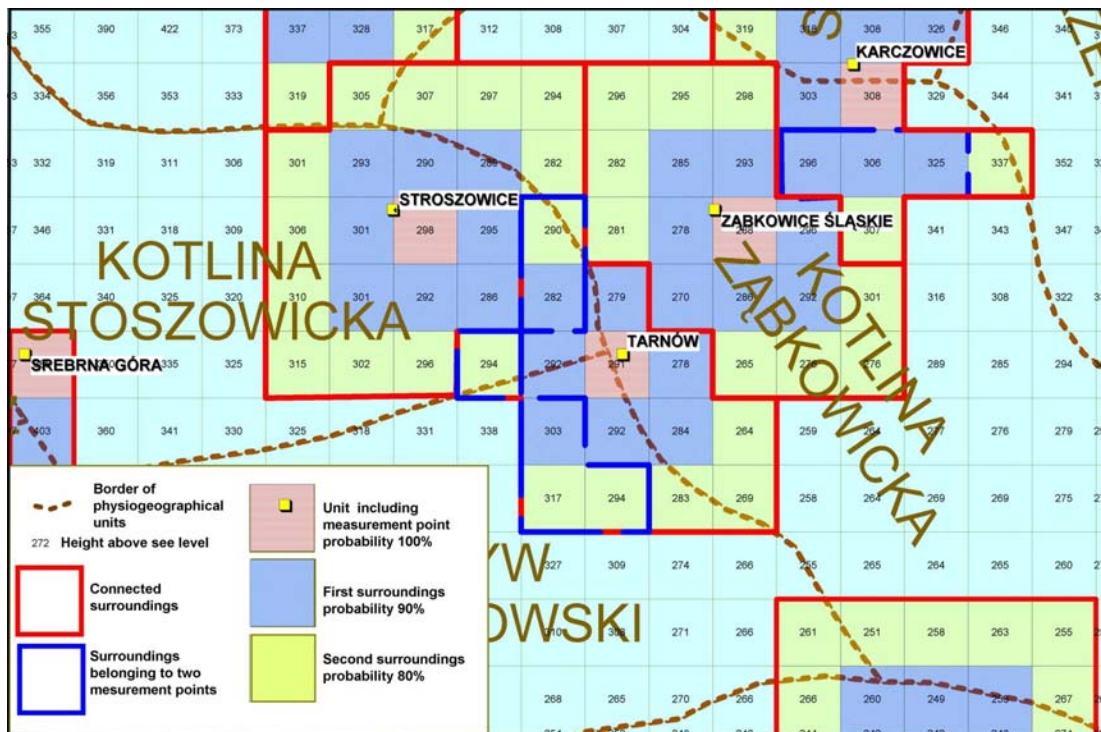


Fig 7. Assigning point information about adequate attributes to elementary fields in spatial information groundwork

BIBLIOGRAPHY

- Aronov, V. I. (1990). *Metody postroenia kart geologo-geofizičeskich priznakov i geometrizaciâ zaležej nefti i gaza na EVM*. Nedra, Moskva.
- Bac-Bronowicz J., Borkowski A. (2003). *On the possibilities of determination of multi-variant reference unit values referred to median rainfall*. Arch. Fotogr. Kart. i Teled. 13a.
- Bac-Bronowicz J., Cieśliński M. (2004). *Reliability of cartographic presentation of spatiotemporal information in Internet related to punctual data consisting of natural elements*. IS GIS. Ostrava. CD. ISSN 1213-2454.
- Bihari Z. (2000). *Mapping of climatological elements in Hungary*. In: 3rd European Conference on Applied Climatology, Pisa, CD. ISBN 88-900502-0-9.
- Boots, B.N. (1987). Voronoi (Thiessen) Polygons. Geo Books, Norwich.
- CORINE <http://www.gsf.de/UNEP/corine.html>
- COST 719 <http://www.knmi.nl/samenw/cost719/wg.htm>
- Fundamentals of physical geography. Chapter 10. (2004).
<http://www.physicalgeography.net/fundamentals/chapter10.html>
- Kondracki J. (2000). *Geografia regionalna Polski*. Wyd. Nauk. PWN, Warszawa.
- Lee, T. J., R. A. Pielke, T. G. F. Kittle and J. F. Weaver. (1993). *Atmospheric Modeling and Its Spatial Representation of Land Surface Characteristics, in Environmental Modeling with GIS* (Goodchild, Parks and Steyaert, eds.), Oxford University Press, New York.
- Pardo-Iguzquiza E. (1998). *Comparison of geostatistical procedures for spatial analysis of precipitation in mountains terrain*. Agric. For. Meteor. 58.
- Podlacha K., Szeliga K. (1999). *Układy odniesień przestrzennych w aspekcie tworzenia i funkcjonowania SIP w Polsce*. Prace IGiK, T XLVI, z 99, Warszawa.
- Thiessen A. H. (1911). *Precipitation averages for large areas*. Mon. Wea. Rev. 39.