

Spatial interpolation
estimation techniques
environmental
sciences essay



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In case of environmental variables, it is observed that they vary abruptly with often strong fluctuations over short distances (Trangmar et al. 1985; Warrcik et al. 1986). Whatever may be the cause of change, the link between spatial dimension and variability of an attribute of interest can be a useful tool for detecting the spatial pattern of underlying variability. A carefully and precisely assessed spatial pattern of variability of an attribute under investigation is often expressed by a mathematical or statistical expression, which can be further utilized for estimation of underlying phenomenon at unvisited or unobserved locations. This idea of spatial variability of an attribute and its estimation within a study area requires collection of sample data adjoined with corresponding spatial addresses in the form of pair of northing and easting per sample. [C]Soil is home to many highly interrelated water, carbon, and vegetation processes. More to this, many micro/macro mechanisms and organisms that control carbon storage, nutrients and contaminant transport to the soil solution, evapotranspiration take place in this part of our ecosystem. Many soil properties not only exhibit spatial and temporal variability significantly, but their detailed and direct measurement is also difficult and cumbersome (Minasny et al., 2011). The past decades has witnessed growing awareness of the importance of characterizing soil properties at un-sampled locations with findings that can be incorporated in subsequent decision-making processes, such as zonal classification on the basis of suitability for crop growth or delineation of contaminated areas (P. Goovaerts 2001). [C]Extensive soil variability together with variation in crop productivity often results in narrow profit margins and environmental pollution. This fact points to the importance of site-specific or precision farming practices, which are found promising on <https://assignbuster.com/spatial-interpolation-estimation-techniques-environmental-sciences-essay/>

controlling environment quality and increasing the profit margins by proper utilization of resources. Site-specific and precision farming practices entail micro-management of agricultural fields to account for field variations induced by natural and human interaction. These variations are often complex with many types e. g. variation in soil type, chemistry and physical properties, moisture, topography, and other factors (T. Panagopoulos et. al, 2005). Precision agriculture includes different management practices for specific soil variable(s) inside farming fields, potentially intended to reducing costs and limiting adverse environmental side effects (Booltink et al., 2001).

[C]

Spatial Interpolation/Estimation Techniques:

In Agricultural applications, spatial interpolation/prediction techniques are extensively utilized due to abundance of environmental variables and their distinctive formations along spatial variations. Soil is a prime factor contributing at most for healthier growth of plants by providing them stability and essential nutrients. Mapping soil attributes (soil pH, EC, Organic Matter (OM), texture, CEC etc.) of an area of interest is often required for decision making processes related to land evaluation, spatial planning, agricultural extension, and environmental protection (Robert M., 1971).

Modern day technological support has replaced conventional soil mapping with Pedometrics— quantitative modelling and mapping of soil properties by using mathematical and statistical methods, with the purpose of analyzing soil distribution, properties and behaviors [?/Number] (www. perdometrics.org). Promotion of pedometrics and bulk processing of soil data distributed in distinct data layers each with a unique property of interest has been

accomplished with the technological support provided by Geographic Information System (GIS)— set of computer programs that can manage, process, analyses and present geocoded datasets. [C]Spatial interpolation methods on the basis of their formulation can be either deterministic or stochastic. Deterministic or mathematical procedures involve modeling of underlying variability of spatial data using predefined mathematical functions. Deterministic functional formulations of study area capture variability either on the basis of degree of similarity or the degree of smoothing, both assessed from geometrical distances calculated between neighboring sample data points. Inverse Distance Weighted (IDW), Thiessen polygon and Radial Basis Function etc. belong to this category of spatial estimation. [C][Potential to Explain more!]However, environmental attributes result from many chemical and biological interacting factors with often non-linear and random patterns along spatial variation, and it is desired to model them on geo-statistical framework. With spatial variations it is often possible to partition them into two distinctive components of variation; deterministic and stochastic variations. Geostatistical techniques use both mathematical and statistical functions to model both components of variation.

Mathematical functions are used to capture deterministic part of variation and statistical functions are added to model the stochastic component of variation using statistical distance functions (covariograms and/or correlogram) as a measure of association or disassociation between neighboring sample data (Isaaks and Srivastava 1989; Burrough and McDonnell 1998; Johnston et al. 2001). Geostatistics is primarily concerned with describing, predicting and conducting uncertainty analysis of spatially varying variables quantitatively by using theoretical and analytical support <https://assignbuster.com/spatial-interpolation-estimation-techniques-environmental-sciences-essay/>

built on Mathematics, Statistics and Geography. [C]Interpolation techniques take advantage of the spatial autocorrelation between sample observations for prediction of same attribute at un-sampled locations within an area of interest. For example, simplest deterministic interpolation technique Thiessen polygon creates a polygon of influence by drawing lines around each sample with sample at the center of polygon and equating sample (value at center) value to each other location inside bounding polygon. In the IDW method, rate of correlations or similarities between neighbors is assumed proportional to the distance between them and it is measured as a reverse distance function of every point from contributing neighbors (Ahmad A, 2011). [C]

Selection of an Interpolation Techniques and Contradictory Findings:

Selection of an appropriate interpolation technique is a key issue and it is usually considered under various important factors including sampling design, spatial structure of study area or variable, data sufficiency and quality, correlation between the primary and secondary variables, and interactions among various physical and biological factors (Li, J. et al. 2011). In literature, there are many contradicting findings about how these factors affect the performance of the spatial interpolators. Contradictory findings of comparative interpolation studies are evident from existing literature in the case of studies when IDW is compared with ordinary kriging. For example, in some studies performance of ordinary kriging outperformed IDW (Kravchenko and Bullock, 1999, T. Panagopoulos et al., 2004 and Kravchenko, 2003). In other studies, IDW generally produce better results

than ordinary kriging (Eldeiry et al., 2011; Weber and Englund, 1992). Often, however, mixed results are also observed (Gotway et al., 1996; and Mueller et al., 2001). [C]Contradictory and inconsistent findings can be attributed to many factors that affect the performance of interpolation methods. Many of these factors emerge out of choices of researchers with the approach to plan and design the study particularly in relevance of sampling design, size, density and spacing etc. It indicates the difficulty to select an appropriate spatial interpolation method for a given input dataset. This literature review effort includes comparative spatial interpolation studies which were aimed to prepare maps of soil quality indicating chemical and biological properties including total mineral nitrogen, electric conductivity (EC), phosphorus, potassium, pH, and Organic Matter, (Cation Exchange Capacity) CEC etc. [C]

Comparative Approach for Selection of an Interpolation Technique

In existing literature, it is found that researchers have used comparative approach for selection of most appropriate interpolation technique for datasets under study. On this course, usually techniques from each category — Deterministic and Geostatistical— are compared and best technique is selected on the basis of quantitative comparison of results. Most of the methods of spatial analysis are primarily based on what described by Tobler as " First Law of Geography": " Everything is related to everything else, but near things are more related than far things" (Tobler 1970). Deterministic techniques are simple and straight forward using mathematical functions of geometric distance with estimation mechanism that observations near to each other are more related than those farther in distance. [C]Geostatistical

techniques on the other hand, depend on the same geography law with sophisticated expressions about distance depicting the spatial structure of study area. Geostatistics include collection of tools that have foundation in classical regression theory and stochastic theory of spatial correlation for interpolation and apportioning of uncertainty (P. A. Burrough, 2001; Isaaks and Srivastava, 1989). Kriging is one such tool that like regression analysis derives a best linear unbiased estimator, on the basis of statistical distance (covariance), and makes use of Gauss-Markov theorem to prove independence of the estimate and error with very similar formulae. The concept of distance remains key input for geostatistical interpolation methods but the notion of autocorrelation (statistical distance) is relied upon and it is assumed that each data value is realization of a random variable of a stochastic space. [C]The basis of geostatistical estimation is the assumption that sample set of a parameter of interest Z inside a spatial design space (Study area) is a realization of a stochastic process which is sum of two components; i. e. , where model the global variability and is postulated as zero mean stationary stochastic process with belong to study Region that is . By incorporating uncertainty factor , conceptualized underhand phenomenon is allowed to be modeled on methodological basis for its spatial inference at unobserved locations with additional quantification of the uncertainty associated with the used estimator. Sample data, selected from finite locations with regular or irregular spacing, is treated as one-time realization of a random function which is considered as intrinsically stationary spatial function. relating sample observations as one-time realizations of corresponding N random variables correlated between themselves and dispersed in stochastic design space at $[]$ locations. With <https://assignbuster.com/spatial-interpolation-estimation-techniques-environmental-sciences-essay/>

one-time realizations sample set from underlying random field it is impossible on theoretical basis to build a required framework to inference about variable of interest or parameters of random function. Under Geostatistical formulism various degrees of stationarity in random function are assumed that helps in building theoretical framework to estimate parameters of random function [Matheron G. 1978]. This weak form of second order stationarity is required to build theoretical basis for analyzing one-time realization of random field in the form of sample. Weak form of second order stationarity is met by two following conditions: where is a lag vector. And variance of the differences depends only on the lag and not on $\gamma(h)$ is the variogram— the variance of the difference between values of a stochastic process measured at two locations across field's realizations (Cressie 1993). Variogram is central to geostatistical interpolation procedures and it is used to capture spatial structure of a dataset (Oliver, 1999). With geostatistical interpolation procedures variogram estimation is crucial input for estimation at un-sampled locations and prior knowledge of its parameters assists in designing grid sampling surveys capable of predicting with target error variance at minimum cost (McBratney et al. 1981). It is also used for simulating spatial structure with same and desired spatial properties for a soil variable of interest (Papritz & Webster, 1995; A. N. Kravchenko, 2003). In practice, the variogram is estimated from sample data and named as " Experimental variogram". Due to limited information contained in sample data from study area it is required that estimated variogram is fitted by a valid function or model on pattern of parameters of experimental variogram for all possible lags inside study area. [C]A number of methods to estimate a sample variogram are available in fundamental <https://assignbuster.com/spatial-interpolation-estimation-techniques-environmental-sciences-essay/>

text (Cressie, 1993) and with the comparative approach best fitting method is selected for a specific dataset. These methods include: least squares, weighted least square, generalized least squares, maximum likelihood, restricted maximum likelihood (REML), minimum norm quadratic estimation (MINQ). Researchers have compared performance of various variogram estimation methods through either simulation data or true field observations (Zimmerman and Zimmerman, 1991; R. M. Lark, 2000; R. Menezes et al., 2005). For example, Zimmerman and Zimmerman demonstrated that the method of ordinary least squares and using Cressie's robust weighted least square estimators (WSL-1 and WSL-2), ML and REML performed better for data simulated by a Monte Carlo simulation study. Kriging as a family of geostatistical estimators includes ordinary kriging, indicator kriging, universal kriging, regression kriging, co-kriging, Bayesian kriging, and their variations. Ordinary kriging is mostly used interpolation techniques due to optimal prediction obtained through minimized prediction error with least variance. Additionally, kriging techniques facilitate estimation procedure with mechanism to take account of direction binding variations between sample locations that can be used to model spatial variation in the surface with directional dynamics (Chil`es and Delfiner, 1999). The general formula for kriging was developed by Matheron (1970). Additionally, geostatistical estimation methods provide standard error of prediction at a specific location which is also useful for calculating confidence interval of prediction at a location of interest. It is this ability of estimating at unknown locations along standard error of estimation and confidence statements about estimate that distinguishes geostatistical prediction methods from the deterministic methods of spatial interpolation. Ordinary kriging, as mentioned earlier, is <https://assignbuster.com/spatial-interpolation-estimation-techniques-environmental-sciences-essay/>

most commonly practiced and most simplistic kriging interpolation technique from geostatistical techniques and often termed simply as kriging. Like IDW it is weighted linear interpolation method and based on the assumption that constant expectation of the random field is not known. Instead of using an arbitrary distance function, OK method use experimental variogram to determine weights for known sample locations contributing in estimation at particular location. Additionally OK method works under the restrictions implemented through equation system which ensures optimal results by keeping mean prediction error equal to zero and error prediction variance minimum. Conventional geostatistical interpolation procedures operate more efficiently when datasets underhand are normally distributed. However, it is observed that many of the geologic and soil properties are often skewed or highly skewed (Journel, 1980; McBratney et al., 1982; Webster and Oliver, 2001). Appropriate transformation of the data alleviates difficulties introduced by such highly skewed datasets. Primarily such datasets are logarithmically transformed (Journel, 1980; Saito and Goovaerts, 2000), to lognormal data. Researchers have used lognormal ordinary kriging as an alternative to ordinary kriging for lognormally distributed data (Rendu, 1979; Robinson and Metternich, 2005; Rivoirard, 1990; Kravchenko and Bullock, 1999). [C][Co-kriging]In early development of soil geostatistics, it was observed that soil could be better predicted if supported by denser sets of secondary variables (spatially cross) correlated with the primary variable. This technique is called co-kriging (A. B. McBratney et. al, 2003). Co-kriging is multivariate extension of kriging. Costly collection of soil attribute sampling data at many locations across landscape has created a need for interpolation techniques that are using data readily available as secondary

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information in order to improve the estimation of soil properties. Such auxiliary datasets primarily belong to topographical attributes (Kalivas et. al, 2002) and their use has the potential to increase time and economic savings in mapping soil properties particularly those for which there are correlated variables (Trangmar et al., 1999). Existing comparative studies have generally found that methods using secondary spatial information support are superior to methods that lack such support (Vaughan et al., 1995; Gotway and Harford, 1996; Gessler et. al., 1995; Rosenbaum and Soderstrom, 1996; Bourenane et al., 1996; Goovaerts, 1997; Zhang et al., 1997; Triantafilis et al., 2001).

Co-kriging has been used to interpolate soil chemicals, $\text{NaHCO}_3\text{-P}$, sodium adsorption ratio (SAR), and soil properties using their spatial covariances with secondary variables such as depth of the soil profile, HCL, electrical conductivity, and terrain indices, respectively (Zhang et al., 1997, Trangmar et al., 1986, Pozdnyakova and Zhang, 1999, and McKenzie and Ryan, 1999). Topography is a dominant control on earth surface processes and influence soil chemical and physical properties (Kalivas et. al, 2002). Early co-kriging studies (McBratney and Webster, 1983; Vauclin et al., 1983; Goulard and Voltz, 1992), utilized as secondary variables other soil variables with strong correlation with primary variable. But later, with improved technological support, detailed secondary data sets of environmental variables derived from digital elevation models (elevation, slope, aspect etc.), satellite images, and GIS maps (Odeh et al., 1994, 1995; Kalivas et. al, 2002; Mueller et. al,

2003; Ahmed Eldeiry et al., 2009) are utilized. Co-kriging takes advantage of correlation that may exist between the variable of interest and other more easily measured variables (Odeh et al. 1995). Co-kriging makes use of the cross-variogram function to transfer the spatial information in the secondary variable to the primary, thus improving the reliability of the interpolation process (Yates and Warrick, 1987, Zhang et al., 1997, and Trangmar et al., 1986). Many studies (Stein et al., 1988; Stein and Corsten, 1991; Zhang et al., 1992, 1997; Istok et al., 1993) showed superiority of co-kriging to ordinary kriging. Others (Shouse et al., 1990; Martinez, 1996) showed that co-kriging was only minimally superior to ordinary kriging when auxiliary variables were not highly correlated to primary variables. As mentioned earlier in the case of kriging, to ensure the validity of the estimates made by cokriging, the cross-semivariograms of the variables must accurately describe the spatial structures of the study area.

[Regression] [External Drift] Regression kriging involves various combinations of linear regressions and kriging. The simplest model is based on a normal regression followed by ordinary kriging with the regression residuals (Odeh et al. 1995). Regression kriging involves spatially interpolating the residuals from a non-spatial model (e. g. OLS) using kriging, and adding the results to the prediction obtained from the non-spatial model (Goovaerts, 1997). In many studies, kriging combined with regression has proven to be superior to the plain geostatistical techniques and yielding more detailed results and higher accuracy of prediction. In several other studies (Odeh et al., 1994, 1995; Goovaerts, 1999b; Bishop and McBratney, 2001; J. Triantafilis et al., 2001; Tomislav Hengla, et al., 2004), combination of kriging and correlation with auxiliary data outperformed ordinary kriging, co-kriging and plain regression.

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Moreover, kriging combined with linear regression has the advantages over the co-kriging method that it uses simpler algorithms, it involves less variogram modelling and the system to be solved is less cumbersome than that of co-kriging (Kalivas et al., 2002).