ON APPLYING AREA AND MULTIPLE FRAME SAMPLING METHODS IN A WIDE RANGE OF BASELINE AGRICULTURAL AND RURAL SURVEY PROGRAMMES

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In this paper we discuss the important role that complex, probability survey designs, and particularly area and multiple frame sampling methods, can play in ensuring accurate data and appropriate agriculture and rural development policies. We refer to large-scale multiple-purpose surveys in a wide variety of statistical programmes in developing countries. We think that these very important survey methods have not been taught, applied or disseminated properly. This paper recommends specific changes to improve the teaching of survey sampling. It also proposes to apply a concrete survey sampling approach, whenever possible: to construct a master area sampling frame on which to base and conduct the area frame survey designs of some of the baseline agriculture and rural survey programmes. Among other aspects, this would facilitate comparison among surveys and provide an integrated view of the Agriculture and Rural sector.

INTRODUCTION

This paper presents observations and ideas on the teaching and application of survey sampling designs, and mainly of those based on area and multiple frame survey methods. It considers the survey design of agricultural and rural surveys, especially baseline national surveys, that is, some of the main large-scale surveys (national or regional probability sample surveys of agriculture, rural conditions, population and housing, fisheries, industry, forestry, health, economic, social, environment, etc.), as well as special studies. It refers to a large spectrum of observations and recommendations on the overall problem of improving the application of appropriate probability survey designs, starting with the teaching of probability theory (with a touch of history) and probability survey sampling. It discusses the important possible advantage of constructing a master area sampling frame on which to base the area frame survey designs of baseline agriculture and rural probability survey designs of a country or region.

Since baseline probability survey designs are an important application of survey sampling, and because it is advantageous to improve them significantly, it is necessary also to improve the teaching of survey sampling, complex designs and specifically area and multiple frame methods and practices. Currently, most countries do not have a valid statistical system based on probability survey methods. As a result, statistical data based on non-probability sampling designs are not able to provide comprehensive data on which to base sound policy decisions. Inaccurate estimates can lead to wrong decisions concerning, for example, agricultural and environmental strategies, policies and food aid allocation and distribution.

The paper, as requested, has been written with the aim of making it comprehensible to statisticians in general and not only to specialists in the meeting's topics.

ON THE TEACHING OF PROBABILITY THEORY

There is an intrinsic difficulty in teaching Probability Theory and therefore Statistics. The definition of probability is difficult, and the corresponding mathematical formulae of many probability models difficult to handle - extraordinarily difficult. Most physical phenomena are only interpreted through probability -or stochastic- models and the mathematics on which they are based is very abstruse, also as a consequence of the difficult definition of Probability. This observation, which is naturally not only of the authors, is often overlooked, but seems to us of great importance.

The Theory of Probability is most possibly the only important mathematical theory not initiated by the Greeks.

The first mathematician (an inveterate gambling scholar) that realized the importance to study scientifically probabilities (chances) for dice games was the famous Gerolamo Cardano around 1520 (cf. [1]). His pioneering work and superb observations did not result in the formulation of a general mathematical definition of probability (his deep insight on randomness considered simple cases and a good understanding of the law of large numbers). It can be said that Cardano was the one who started the discovery of the Theory of Probability during the Italian Renaissance. Some of the best scientific brains, during the next 500 years, didn't realize the importance of Cardano's findings. Cardano's work was too advanced for his time, and when more than a hundred years later other mathematicians attacked the problem of probability, his work was ignored. Then, as already mentioned, some of the best mathematicians of the XVII century (Pascal and Fermat around 1650), and of the XVIII century (Jacques Bernoulli) dedicated many years of their lives to give a mathematical definition of probability and to better study problems of a random nature.

The Marquis Pierre-Simon de Laplace, around 1810, was the one that finally was able to discover a mathematical definition of probability (cf. [3]). But such definition is quite restrictive and therefore cannot be used for many applications. *Quoting Laplace from his* Philosophic Essay on Probabilities*: "It can be seen in this Essay that the Theory of Probability is, deep down, none other than common sense reduced to a calculus;...We will see that there is no science more worthy of our reflexions and whose results are more useful".*

The importance of the Theory of Probability, as indicated by Laplace, is today obvious and phenomenal: modern physics, biology and natural sciences are now mainly based on different probability models. This has being one of the most important scientific discoveries of the last century (however, it may seem curious that Einstein did not recognize the importance of stochastic models. The future of science is very difficult to foreseen, even by the best scientists).

In 1933, a notable achievement occurred: the eminent Russian mathematician A. N. Kolmogorov published in English a short book in which he included the definition of probability as part of a Space of Probabilities (cf. [19]. Kolmogorov achieved what celebrated mathematicians and scientists since Cardano, in the XV century, were not able to do: to include the Theory of Probability as a chapter of Mathematical Analysis. Kolmogorov was able to include in mathematics the study of chance randomness in a very general way. The Theory of Probability belongs since then to Mathematics. Later, even more general Probability Spaces (for example including conditional probabilities) are used, spaces that encompass the great majority of applications. This allowed, in turn, a phenomenal achievement: to provide a solid basis to Statistics.

The above-mentioned brief history it is an outstanding example of science trying to study the complexity of reality. The mathematical basis of Informatics and the Theory of Probability are the two most important contributions of mathematics to the Physical Sciences and technological applications, which have changed the way of life for millions of people.

ON THE TEACHING OF MORE COMPLEX PROBABILITY SURVEY DESIGNS

The Marquis Pierre-Simon de Laplace (1812) was the mathematician who initiated the study and use of Probability Survey Sampling. Later, Lambert Adolphe Jacques Quetelet (1835), who studied with Laplace and Fourier, is considered by many to be the father of Survey Sampling. This may be because he was the first to use the normal curve and apply probability statistical methods to many practical problems. Since that time, a number of distinguished scientists have made important contributions, but really probability survey sampling underwent an extraordinary development after the Second World War in 1945. As a consequence, in the 1960s, a number of statistically developed countries made great efforts to introduce probability sampling designs for their baseline surveys, replacing the previously used purposive (or non-probability) sampling designs.

The introduction of large-scale probability sampling methods for the purpose on generating baseline national statistics still has not been done in most countries of the world. The recognition of the importance of applied statistics and in particular probability survey methods is, unfortunately, not frequently recognized among policy makers and even technical experts.

The only way to formulate serious policies is to have sound, reliable and timely statistics on the subject of interest. Also because, in the worst of the cases, as Lucius Annaeus Seneca said, "The predicted misfortunes become lighter".

By definition, timely and reliable large-scale baseline surveys can only be provided by establishing adequate sampling designs based on probability sampling and estimation methods. The teaching and application of probability survey designs should be promoted. Survey sampling textbooks should be greatly improved for the teaching of statistics by including much more emphasis on complex multiple-purpose survey designs, and the comparison among them.

ON THE CONVENIENCE AND POSSIBILITY OF APPLYING MORE COMPLEX SURVEY DESIGNS TO IMPROVE LARGE SCALE BASELINE SAMPLE SURVEYS

The use of inappropriate survey designs for large-scale baseline national surveys as part of the National Statistical Programmes has been common in most countries for many years, and this has always led to harmful results. Many countries have used purposive surveys and have not applied probability survey designs. For example, before the fall of the Berlin wall, in the communist countries in Africa, America, Asia and Europe (including China and in the former Soviet Union), probability survey designs for baseline surveys did not exist, and statistics were distorted for political reasons. Over time, this resulted in a lack of knowledge of their populations, production, their social and economic conditions, and other key data. As a result, those countries could not foresee their necessities. In other countries, Governments were unable to predict their necessities because of the use of inappropriate survey designs (i.e. non-probability or overly simplistic survey models). In some cases, a statistical crisis had led to the improvement of survey programmes. As an example, in 2008 a country in Asia estimated a surplus in wheat and therefore sold 500.000 tons. Three months later it became obvious that the country was short on wheat and had to purchase on the world markets one million tons of wheat at twice the price. The lessons learned from these experiences include the following:

- In most cases it is convenient to teach and apply much more complex, multiple-purpose survey designs for most baseline statistics in order to provide more reliable and timely data.
- The study and treatment of outliers should be improved. And nonsampling errors should be considered more carefully. The emphasis of these topics in survey sampling textbooks should be improved, since the most important aspect of survey sampling is its application.
- It will be critical to teach and use, on a much large-scale, modern informatics and related techniques. This will include computer techniques and instruments, as well as satellite data, images and photos. There are more facilities than ever before for decisions to be taken based on accurate, reliable and timely statistics. The current limited use of computerized techniques and instruments is somehow a paradox in the era of informatics and communications, in the era of John von Neumann, Norbert Wiener and Claude Shannon (the first two, pure mathematicians). Because now there is a widespread availability throughout the world of computers, software and computerized instruments. For example, geographic information systems (GIS), geographic positioning systems (GPS), portable computers for data collection, satellite data images and photos, computerized area measurement and scale-

transfer instruments, statistical software for data entry, processing and analysis; all this tools being an enormous advantage also for the application of complex survey designs. However, none of these instruments or software can substitute knowledge of survey sampling, quality control procedures and sound statistical designs. For the purpose of designing and conducting probability surveys the new digital instruments and software by themselves are of no use, contrary to the belief in many countries and occasions. Knowledge is more important than money in most developing countries. However this last statement may not be in fashion.

What is more critical, in order to improve the precision of the estimates, is to apply much more complex probability survey designs that use more computerized techniques and instruments, to take advantage of the enormous progress in Informatics.

THE DEVELOPMENT OF AREA AND MULTIPLE FRAME SURVEYS. TEACHING AREA AND MULTIPLE FRAME PROBABILITY SURVEY METHODS

Area frame designs where first developed in the United States by Earl E. Houseman and Raymond J. Jessen in the 1940s (cf. e.g. [15]), and around the same time in India by Chandra Mahalanobis (cf. [20]). Multiple frame survey designs, were first introduced by H. O. Hartley in the 1960s (cf. e.g. [12] and [13]), and applied in the Annual Agricultural Survey conducted by the USDA (United States Department of Agriculture). Later, several USDA top statisticians (cf., e. g. the bibliography in [9], Vol. II) were responsible for fundamental developments in the theory and application of multiple frame surveys including the use of satellite imagery and data, a decisive improvement. Those statisticians accomplished an unparalleled theoretical and applied development in these multiple-purpose agricultural survey designs (cf., e.g., [11], [14], [21] and [26]). Also, with funding from NASA, USAID (United States Agency for International Development) prepared an ad-hoc geographic information system called CASS-Computer-aided stratification and sampling-. As a consequence, by 1994, in each state of the USA, the construction of the sampling frame and the sample selection were implemented using the CASS (cf., [25]).

Over more than thirty years, a variety of area and multiple frame survey designs (on various topics) were also applied in dozens of countries or regions of countries around the world, by international statisticians by using modifications of methods and procedures to adapt the designs to their special needs (cf., e.g., [6], and the bibliography in [9], vol. II). For instance, since the 1990s, in a number of countries multiple frame survey designs were implemented by using standard GIS for the area frame construction.

In a previous paper (cf. [8]) it was noted that the classical textbooks on survey sampling, indeed the ones from which many persons still learn sampling (or consider them as the main references), do not include area or multiple frame methods. These classical textbooks are from the following authors (in chronological order of publication): Yates, F. (cf., [27]); Deming, W. E. (cf., [4]); Cochran, W. G. (cf., [2]); Hansen, M. H.; Hurwitz, W. N. and Madow, W. G. (cf., [10]); Sukhatme, P. V & Sukhatme, B. V. (cf., [24]); Kish, L. (cf., [17]); Zarkovich, S. S. (cf., [28]); Desabie, J. (cf., [5]); Murthy, M. N. (cf., [22]); and Raj, D. (cf., [23]). Even a more recent book on agricultural surveys sponsored by a UN International Agency did not include multiple frame designs, although those designs have been used for decades in many countries as mentioned in the previous section (cf., e.g., the 1989 FAO publication [18]). Many recent books on survey sampling also do not include area or multiple frame designs. In addition, the study and treatment of outliers and the control of nonsampling errors are not addressed properly in most survey sampling textbooks.

Therefore, area or multiple frame survey designs, used successfully since the 1940s, are still *not* included in the classical survey sampling textbooks, which are, by far, the main source of learning survey methods and applications. This is, in our view, an important issue that has to be modified in future books on survey methods. The probable reason of this unfortunate fact is explained, for example in [8].

Survey Sampling textbooks should be greatly improved in the teaching of statistics by including much more emphasis on area and multiple frame survey designs, and also give proper importance to the study of outliers and nonsampling errors in surveys.

THE CONSTRUCTION OF A MASTER SAMPLING FRAME ON WHICH TO BASE SOME OF THE MAIN BASELINE AGRICULTURAL AND RURAL AREA FRAME SURVEYS

In view of the reasons already explained, whenever possible (and convenient) one should implement stochastic models for periodic (say annual or quarterly, for example) agricultural and rural surveys based on area or multiple frame probability survey methods.

Multiple frame designs are complex survey designs that have the advantage incorporating two complementary components: an area sample in which the units are geographic areas, combined with list samples selected by using list frames of farms, establishments, housing units, etc. (cf. e.g. [9], Vol. I). The design could have then the advantages of both the area sample and the list samples. The area sample design could consist of a stratified probability sample of *segments* (geographic areas), with a replicated selection procedure. The list frame samples (which should be regularly updated) should ensure the inclusion of those farms, establishments or housing units (or other units of study) that will make a significant contribution to the total estimate of some important survey variables, improving therefore the precision resulting from the area sample component alone.

A large number of criteria are used to establish and appropriate agriculture and rural survey programme. Different data users can place different emphasis on their relative importance. Some of the advantages, disadvantages and applications of multiple frame designs versus list frame designs are given, for example, in [9], [14] and [26]. A brief résumé may be appropriate here:

- *Comprehensive agricultural and rural survey programme that would allow data comparison among different surveys.* To support decision-making, an agricultural information system must provide data on all aspects of the agricultural sector. As mentioned, there is a very important advantage if a country or large region can establish a master area sampling frame on which to base the survey designs of the main baseline agriculture and rural surveys; among other aspects, this would allow comparison among surveys, facilitate the determination of relationships between and among variables, and have an integrated view of the sector. Most important, these methods will facilitate the collection of a large variety of data as recommended by the Millennium Development Goals (MDG), that requires data on agriculture, environment, natural resources, health and social sectors to support program planning, namely to: 1) eradicate extreme poverty and hunger, 2) achieve universal primary education, 3) promote gender equality and empower women, 4) reduce child mortality, 5) improve maternal health, 6) combat HIV/AIDS, malaria and other diseases, 7) ensure environmental sustainability, and 8) develop a global partnership for development.
- Most developing countries do not have survey programmes that can obtain and compare such variety of required data. Area frame survey methods may be, in many cases, the most practical way to obtain most of the required comprehensive data.
- *Data Reliability*. By definition, the difference between the sample result and the result from a complete count taken under the same conditions is measured by the *precision* or the *reliability* of the sample result. It is essential to have probability survey designs since, by definition, there is no other way to obtain reliable data. Area frame designs provide a much more precise, better definition of the sampling Universe (in practice, a complete list of farms, establishments or housing units cannot be constructed in such a way as to be valid for the data collection period), and therefore area frame designs define better the probabilities of selection and the sampling method. Therefore, area frame surveys are better and more precisely defined survey designs

than list frame designs. Reliability is what gives data credibility and credibility is crucial to ensure that data are useful.

- *Coverage*. An area frame provides a complete coverage of the population of information units; it can be used for a vast variety of surveys on different topics; provides much easier methods for measuring areas; and if it were an agricultural survey, the construction of the area frame is independent of the farm boundaries or farm products.
- *Accuracy of the Sample Survey. Nonsampling errors.* By definition, the difference between the sample result and the true value is called the *accuracy* of the sample survey, which is a most important characteristic. Accuracy is a function of two types of survey errors: sampling errors and nonsampling errors. Nonsampling errors often cannot be measured, can only be controlled. They need to be addressed specifically because they are pervasive. Nonsampling errors account for a large portion of errors in most agricultural and rural survey programmes. In many countries around the world, survey programmes are dominated by nonsampling errors. These nonsampling errors can be reduced greatly by clear definitions and procedures and improved survey designs. Nonsampling errors are due to many reasons, for instance: using poorly defined concepts, incomplete sampling frames, outdated lists, data collection that has no field checks, entering or summarizing data improperly, using samples that are too huge to be managed and supervised, lack of proper monitoring in the different aspects of the survey programme, etc. In addition to those reasons, in some cases it has been observed that data are manipulated (changed) by officials to make their programs seem better than what they really are. A way to reduce nonsampling errors is therefore to control (i.e., try to reduce) each one of the causes of biases. In many cases, sample data can be improved. In the opinion of the authors, unfortunately, many agricultural and rural survey programmes lack reasonable accuracy (cf. [7] and [16]). Area frame probability surveys give, in some cases, more accurate data than list frame surveys, mainly by facilitating a better control of nonsampling errors.
- *Facility in using more advanced and precise technologies, particularly based in informatics*. There are several types of advanced methods that usually complement, improve or are facilitated by a purely area frame design: a) multiple frame sampling or two-frame sampling where lists frames of special farms are used, as already mentioned; b) satellite data is used in GISs (geographic information systems) that allow to construct more precise sampling frames and facilitate sample selection, c) satellite digital analysis is used for small area estimates, and d) objective yield surveys are much easier to conduct (crop-cutting surveys at harvest), and the costs for such studies is reducing drastically. All these technologies can be accommodated much more easily with area frame designs than with the more classical list sample designs, and they help make most efficient survey designs.
- *Cost of the survey design and the survey programme.* Area frame designs have the advantage of being cluster designs, with much lower data collection costs than most list samples; the precision of the estimates could be reduced after years of use, but the estimates are unbiased; the maintenance of the area frame is generally cheaper than the cost of updating of a list frame. However, the construction of an area frame requires more cartographic support than the construction of list frame, and therefore higher costs. The use of satellite imagery or data for the construction of an area frame and sample selection were in the past an important issue, many times so decisive that countries did not apply area frame surveys because of the cost involved, but nowadays, such costs have been reduced so much that, in most cases, do not constitute a restriction anymore. The overall costs along the years of an area frame sample survey programme could very well be lower than that of a list frame survey programme.
- *Timeliness.* Agriculture is dynamic and therefore extremely demanding. Drastic changes can occur in a short period of time due to natural causes. Decisions affecting the present and future food supplies are crucial. In agricultural policy formulation unless data are timely, it is nearly useless. Planners and policy makers want to use the world markets to their advantage if they are buying or selling commodities. For that purpose, they must have timely data on agricultural production. Area frame survey programmes can also provide timely data using subsamples.
- *Sustainability.* A sustainable large-scale survey programme is quite uncommon. An area sample survey programme has the relative advantage of motivating the personnel involved in

the project due to its objectivity. On the other hand, in most cases they require much more technical expertise and cartographic resources (use of GISs including satellite data) than list frame designs with similar purposes. To reduce this problem, it may be appropriate to involve data users in order to make more likely that expertise and funds would be available. Consultants, external resources and funds may be the only way to establish a sound, appropriate survey programme in a country. But, experience shows that great emphasis should be given in providing proper training and knowledge to local personnel in order to allow them to maintain and conduct the survey programme without external assistance. Even now, after many failures, many technical assistance programmes do not meet the above criteria.

- *Flexibility*. A survey programme must be able to be adapted without having a massive redesign because of new requirements like changes in land use. This could be achieved by establishing a master area frame, as suggested, if different topics are required.
- *Ability to detect change*. Area frame methods are specifically designed to measure change. In an annual survey, for instance, it is most important to know the estimate of change from a previous year. Results of surveys where data collection was done at different times should reflect real changes in the target population and not changes in the survey methods or sample. The usefulness of statistical data increase when time series data are available for comparison.
- *Disadvantages of an area frame survey*. One of the important disadvantages of an area frame design is that it requires personnel with much higher qualifications, for example: survey statisticians with knowledge of complex designs, estimation procedures, treatment of outliers, data comparison with other sources, adjustment of data, improvement of the survey quality and data analysis; cartographers familiar with GIS; some field data collection personnel familiar with satellite imagery; experts (in several fields) in area frame construction and maintenance. An area frame is generally much more difficult to construct than a list frame (although a list frame is, in practice, incomplete, or biased or outdated, as stated). Finally, let us say that the estimation procedures of multiple frame surveys are much more complex than those of list frame surveys, in which often the sampling units have a one-to-one correspondence with the information units.

FINAL CONSIDERATIONS AND POSSIBLE SOLUTIONS

As a consequence of the arguments given so far, and taking also into account the views of many distinguished colleagues, it is suggested to decisively improve the teaching and knowledge on agricultural and rural survey methods by including in the "curricula" of survey sampling at least three methods that are of common use for the design of multiple-purpose agricultural and rural statistics: area sampling and multiple frame sampling.

The teaching of most appropriate and better agricultural survey sampling methods for large-scale surveys should now also take into account more complex, multiple-purpose survey designs, the teaching of informatics techniques and the much more intensive use of computerized instruments for many aspects of the surveys. And not only because these techniques, software and computer instruments are useful in combination with the survey methods, but because, as already mentioned, even if it seems incredible, they are *available* in most countries, even in developing countries. In those countries, what is most needed is educated and knowledgeable persons, not money or instruments, as some people think.

It has been emphasized the convenience, whenever possible, to construct a master area sampling frame on which to base the survey designs of some of the main baseline area frame agriculture and rural survey programmes of a country or region. Multiple frame survey designs may be the most practical way for a country or a region to produce the required periodic reliable and timely basic data for the agricultural and rural sector.

It is needed, through better statistics, to improve the knowledge on the conditions of living of millions of persons that live in misery. It is necessary to know in order to improve.

REFERENCES

[1] Cardano, Gerolamo (1520). *LIBER DE LUDO ALEAE*. English translation from Latin, (1953). Holt, Rinehart & Winston, New York.
[2] Cochran, W.G. (1977). Sampling Techniques. Third edition, *John Wiley and Sons,* New York.
[3] de Laplace, Pierre-Simon (1810). *Théorie Analitique des Probabilités*. Courcier, Paris.
[4] Deming, W. E. (1960). Sample Design in Business Research. *John Wiley & Sons,* New York.
[5] Desabie, J. (1966). Théorie et Practique des Sondages, *Dunod,* Paris.
[6] Gallego, F.J., Delincé J. & Carfagna, E. (1994). Two stage area frame on squared segments for farm surveys. *Survey Methodology, 20 (2): 107-115.*
[7] Gentle, J., W.H. Wigton, and C. Perry. (2006*). Modeling Nonsampling Errors in agricultural surveys, JSM*, August , San Francisco.
[8] González Villalobos, A. (2006). *Sample Survey Statistics Teaching: An Almost Worldwide Problem on Teaching Agricultural Survey Methods*, Invited Paper at the ISI/ICOTS 7.
[9] González Villalobos, A. & Wallace, M. A. (1996/2001). Multiple frame agricultural surveys - Agricultural survey programmes based on area frame or dual frame (area and list) sample designs, Vols. I and II; *FAO, Statistical Development Series 7 and 10,* Rome. ISSN 1014-3378. Published in English, Arabic, Chinese, Farsi, French and Spanish.
[10] Hansen, M. H.; Hurwitz, W.N. & Madow, W.G. (1953). Sample Survey Methods and Theory. Vols. I-II, *John Wiley and Sons*, New York.
[11] Hanuschak, G.A., Allen, R.D. & Wigton, W.H. (1982). Integration of Landsat data into the Crop Estimation Program of USDA's Statistical Reporting *Service* -1972-1982. *Invited paper. Machine Processing of Remotely Sensed Data Symposium, Purdue University, Indiana, USA.*
[12] Hartley, H.O. (1962). Multiple frame surveys. *ASA Pro. So. St.*, 203-206.
[13] Hartley, H.O. (1974). Multiple frame methodology and selected applications*. Sankhya, Series C, 36, 99-118.*
[14] Houseman, E.E. (1975). Area frame sampling in agriculture. *Statistical Reporting Service, Report No. 20, USDA*, , Washington, D.C. *Spanish version, 1976.*
[15] Jessen, R.J. & Houseman, E.E. (1944). Statistical investigation of farm sample surveys taken in Iowa, Florida and California for obtaining farm facts. *Res. Bull. Iowa St. Univ., 329: 263-338.*
[16] Keller, T., W.H. Wigton et al. (2003). *Composite Estimation for Crop Yields.* USDA/NASS. Washington, D.C.
[17] Kish, L. (1965). Survey Sampling. *John Wiley and Sons*, New York.
[18] Kish, L. (1989). Sampling methods for agricultural surveys. *FAO Statistical Development Series No. 3*, FAO, Rome.
[19] Kolmogorov, A.N. (1933). Foundations of the Theory of Probability. *English translation from the German (1950). Chelsea Publishing Co*., New York.
[20] Mahalanobis, P.C. (1944). On large-scale sample surveys. *Philosophical transactions of the Royal Society of London. Series B, 584 (231): 329-451.*
[21] Moore, R.P. (1969). Research report on four state multiple frame study. *Statistical Reporting Service Staff Report, USDA.* Washington, D.C.
[22] Murthy, M.N. (1967). Sampling Theory and Methods. *Statistical Publ. Society*, Calcutta.
[23] Raj, D. (1972). The Design of Sample Surveys. *Mc Graw-Hill,* New York.
[24] Sukhatme, P.V & Sukhatme, B.V. (1970). Sampling theory of surveys with applications. Second edition. *Asia Publication House*, London.
[25] USDA. (1994). *CASS*. Computer-aided stratification and sampling. Washington D.C.
[26] Vogel, F.A. & Bosecker, R. (1974). Multiple frame livestock surveys: a comparison of area and list sampling. *Statistical Reporting Service, USDA*, Washington, D.C.
[27] Yates, F. (1981). Sampling methods for censuses and surveys. 4th ed., *Griffin*, London.
[28] Zarkovich, S. S. (1965). Sampling methods and censuses. FAO, Rome.