

A BRIEF REVIEW OF GEOINFORMATICS ANALYSIS ON POVERTY DATA IN INDONESIA

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ABSTRACT

A research group on geoinformatics was built in 2010 at Department of Statistics of Bogor Agricultural University, Indonesia, to implement statistical analysis on spatial data. The initial step was to compile some statistical methods related on geographical regression of the simple approach and the complex ones. The methods were implemented to analyse the poverty data in Indonesia. Outcome of selected models was on poverty indicators in a district, such as percentage, expenditure per capita. The outcome was a priory influenced by some regional factors, i.e. local government policy, agro-climate typology, as well as local socio-culture. Therefore, the type of data may produce problems of outliers, outcome dependency, and non-stationarity. Classical approaches assuming there is no effect of the regional differences are not valid any more. For the first phase, the group then implemented methods related on GWR (Geographically Weighted Regression) including simultaneously or conditionally autoregressive models. To obtain firm statistical conclusion, the selected models were contrasted to the ordinary regression. The result indicated that district or regions affected on the poverty level. Hence, spatial factors cannot be neglected in analysing poverty in Indonesia. Additionally, geographical regression performed better than the ordinary models.

Keywords: geographical regression, regional factors, non-stationarity, spatial data

1. INTRODUCTION

Many statistical approaches in geo-related sciences (geo-sciences) including social and environmental sciences have been developing rapidly due to the need in analyzing spatial data. The data found in these areas are usually based on observational study affected by geographical factors of both natural and non-natural effects. The natural factors may come from the type of agro-ecological typology, while the non-natural ones are due to the local governmental policies and socio-cultural aspects which may vary

from place to place. In addition, the usual object of study is spatial unit comprising individuals or household in specific places. These conditions will inevitably introduce the problems of spatial heterogeneity, spatial non-stationarity, and spatial dependency in which the data are obtained. Spatial heterogeneity violates the assumption of variance homogeneity of model residuals (see for example in Getis and Ord, 1992) termed as error propagation by Haining (2004; Section 4.1.3). Spatial non-stationarity causes non-representativeness of global regression models explained nicely by Fotheringham, Brunson and Charlton (2002). Spatial dependency violates the assumption of residual independence of regression models. In brief, standard statistical approaches are not appropriate any more and need some adjustment in analyzing spatial data. Otherwise, the models will produce misleading conclusion and recommendation. Anselin and Sergio (2010) provide a comprehensive review of literature on spatial statistics encompassing spatial analysis, pattern analysis, local statistics, and application. Spatial data analysis is commonly implemented in the regional science which includes economic, epidemiology, public health, and environmental sciences. Haining (2004) provide an excellent book related on the theory and practice of spatial data analysis.

Indonesia lies between latitudes 11°S and 6°N with longitudes 95°E and 141°E, a large country with 497 regencies and administrative cities spread out in 33 provinces. The variability of spatial data cannot be avoided due to the natural factors as well as non-natural ones including the local governments. The local governments in Indonesia since 2000, according to the national regulation, have obtained their autonomy to govern the local programs except for the international policies. Therefore, the local policies will inevitably induce variabilities of some socio-economic variables. In brief, applying adequate methods related to spatial data is getting crucial in the country. Therefore the Department of Statistics of Bogor Agricultural University has initiated to run research and development in spatial statistics under a group named Geoinformatics. The objectives are to compile, to develop, and to implement spatial statistics in poverty data in Indonesia. Poverty data is an appropriate example for applying spatial statistics as the poverty is affected by the natural and non-natural factors. The term of geoinformatics is interchangeably used with spatial statistics or geo-statistics. However, the GIS (Geographic Information System) part is not elaborated deeply in the paper making a more complete definition of geoinformatics according to Patil (2005) is not fully followed. The approach is concentrated on statistical modeling and analysis.

Poverty is one of the many complicated problems in developing countries which may be related to each other. Spatial statistics is a powerful method to analyze factors causing poverty. First step to recognize the poverty of data is to implement EDA (exploratory data analysis) including descriptive statistics to summarize data property. In addition, EDA following Good (1983) may detect the pattern of data, identify interesting behaviour of data, recognize some errors and outliers, and formulate some hypotheses. In relation to spatial data, the EDA may be termed as ESDA (exploratory spatial data

analysis) in which 'location' factor is included in the analysis (Haining, 2004). The ESDA is then very useful to firstly recognize the characteristics of data in a specific region or factors related to the location (space). However, more detail analysis related to statistical relationship, cause-effect models, and prediction are not facilitated in the EDA or ESDA. Davenport and Harris (2008) mention that the more complicated the problems the more statistical intelligent is needed, including statistical analysis and modeling. However, descriptive statistics in EDA/ESDA is still a prerequisite for advanced statistics.

2. PRELIMINARY RESULT

In this section preliminary results related to standard spatial statistics are described, i.e. descriptive statistics, geographically regression and autoregressive models for spatial data. The rest of the approaches are covered partially in the section of model development. The more complex models related to overdispersion, random effect models, and spatial generalized linear models are not elaborated yet in this paper. Hence the paper concentrates on simple approach but very important to consider.

2.1. Descriptive Statistics

Descriptive statistics found that the poverty in Indonesia is related to local government, i.e. country, district and regency, geographical relative position, shoreline, relative position from the forest, income and expenditure, housing condition, health and education facility, type of drinking water, accessibility, and many other factors related to socio-economic condition (Saefuddin *et al* 2011). In terms of covariates, Saefuddin *et al* (2011) also found that poverty in Indonesia is a function of main family income, transportation infrastructure, energy used for cooking, and local basic need facilities especially for education, health and economic activities. Unfortunately the ESDA cannot provide deeper information related to correlation between variables, estimation, prediction, and other advanced statistics. The group hence implement some statistical method related to spatial data, i.e. Spatial Regression, Geographically Weighted Regression (GWR), Spatial Autoregressive Regression (SAR), Conditional Autoregressive Regression (CAR), SAR Poisson, Spatial Empirical Best Linear Unbiased Prediction (SEBLUP), Spatial Bayesian Model of Small Area Estimation (SB-SAE), Hot-spot in SAE, GWR-Poisson Models. Some of the approached have been reported in MSc thesis and journal publications, while the rests are still in the research process for MSc and PhD levels. However, in this paper the author concentrated only in geographically weighted regression and autoregressive models which have been implemented by the group to analyze poverty in Indonesia.

2.2. Geographically Weighted Regression

In regional based modelling, the ordinary regression (OR) models provides global parameter estimates (β s) assuming there is no spatial variation over regions, i.e. spatial stationarity. Unfortunately, if the assumption is not fulfilled by empirical data, i.e. spatial non-stationarity, the global estimates will not be reliable. Theoretically the parameter estimates are unbiased and applicable universally to all areas of study. Also, the models do not provide specific parameter estimates depending on the locations. However, geographically Weighted Regression (GWR) is relatively a new alternative approach to construct model on spatial non-stationarity condition (Brunsdon, Fotheringham and Charlton 1996, 1999; Fotheringham, Brunsdon and Charlton 2002). This approach is applied to test the structural stability of the predictors over region because data non-stationarities can compromise global result (Lambert, McNamara and Garrett 2006). By using GWR, it allows to estimate local models and produce local statistics specifically for every region. Fotheringham, Brunsdon and Charlton (2002) provide detail comparison between global and local estimates which is re-presented in Table 1.

Table 1. Differences between local and global statistics

Global	Local
Summarize data for whole region	Local disaggregation of global statistics
Single-valued statistic	Multi-values statistic
Non-mappable	Mappable
GIS unfriendly	GIS friendly
Aspatial or spatially limited	Spatial
Emphasize similarities across space	Emphasize differences across space
Search for regularities or 'laws'	Search for exceptions or local 'hot-spots'

(Source : Fotheringham, Brunsdon and Charlton, 2002, pp. 6)

Suppose, response variable of n observations of is formed as a linear function of p predictors. In OR, the model will be generally expressed as

$$y_i = \beta_0 + \sum_{k=1}^p \beta_k x_{ik} + \varepsilon_i \quad (1)$$

where y_i is the outcome of i -th observation, x_{ik} is i -th observation of k -th predictors, β_k is k -th regression parameters ($k=1,2,\dots,p$) and ε_i is error term that follows normal distribution with zero mean and known standard deviation and $i=1,2,\dots,n$. In matrix notation, if X is an $n \times (p+1)$ matrix of predictors, Y is an $n \times 1$ column vector of responses, β is an $(p+1) \times 1$ column vector of parameter and e is column vector of error term, Equation (1) can be written as

$$y = x\beta + e \quad (2)$$

OLR model is applied to all regions universally. However, in spatial case, it may be reasonable to assume that the effect of a predictor is conditional upon localized, unobserved factors and social networks (Lambert, McNamara and Garrett 2006). GWR method generates local model for every region, hence spatial effect could be accommodated better than a global model does. GWR is an extension of weighted regression in which the weighting function is based on the relative position among regions. The higher weight is assigned to nearby observation then it will decrease continuously when the distance farther away.

GWR could be applied on linear regression (Brunsdon, Fotheringham and Charlton 1996, 1999, Fotheringham, Brunsdon and Charlton 2002, Propastin, Kappas, and Muratova 2006, Pavlyuk 2009, Shariff, Gairola and Tahib 2010, Rahmawati 2010, Saefuddin, Setiabudi and Achsani 2011), binomial logistic regression (Atkinson, *et al* 2003, Luo and Wei 2009, Windle *et al* 2009) and Poisson regression (Nakaya *et al* 2005, Lambert, McNamara and Garrett 2006). GWR has been applied widely in environment and urban planning (Atkinson *et al* 2003, Propastin, Kappas, and Muratova 2006, Luo and Wei 2009, Shariff, Gairola, and Tahib 2010), public transportation (Pavlyuk 2009), socio-economic (Brunsdon, Fotheringham and Charlton 1996, Lambert, McNamara and Garrett 2006, Rahmawati 2010), property (Brunsdon, Forteringham, and Charlton 1999), demographics study (Saefuddin, Setiabudi and Achsani 2011), agriculture and fisheries (Windle *et al* 2009), epidemiology (Nakaya *et al* 2005) and many other applications in epidemiology and health. Until now, however, the use of the GWR in Indonesia is very limited. This paper is to review research result related to application of linear GWR on demographic study in Indonesia.

Equation (1) or (2) is considered as global model. Then if linear GWR model is applied, each i -th region of interest will have its own local model expressed as

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^p \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \quad (3)$$

where (u_i, v_i) is location of i -th observation, or on the other word the centroid of i -th region (Fotheringham, Brunsdon and Charlton 2002). Suppose the diagonal elements of an $n \times n$ matrix $\mathbf{W}(u_i, v_i)$ consist of the weight at region (u_i, v_i) . In matrix notation, for given y_i , then

$$y_i = \mathbf{X}_i(\mathbf{X}_i^T \mathbf{W}(u_i, v_i) \mathbf{X}_i)^{-1} \mathbf{X}_i^T \mathbf{W}(u_i, v_i) \mathbf{y} \quad (4)$$

The $\mathbf{W}(u_i, v_i)$ would be vary as (u_i, v_i) is changed depending on its location (Leung, Mei and Zhang 2000a). When all elements of $\mathbf{W}(u_i, v_i)$ remains constant over region, the ordinary weighted regression is held. However, in GWR, the weight at region i -th correspond to j -th region, $w_j(i)$, is a function of distance of two regions, d_{ij} ($j = 1, 2, \dots, n$).

To define weighting function, there is two common method can be applied, i.e. Gaussian function and bisquare function (Brunsdon, Fotheringham and Charlton 1996; Leung, Mei, and Zhang 2000; Fotheringham, Brunsdon and Charlton 2002). Related to the process of choosing the weighting function, it is very important to predetermine an optimum bandwidth. This could be done by minimizing either cross-validation score or Akaike Information Criteria (Forteringham, Brunsdon and Charlton 2002).

Regarding to residual sum of squares (RSS), GWR almost performs better than OLR does. However, GWR model needs statistical test to examine whether difference between RSS of GWR and RSS of OLR model, commonly named as GWR improvement, is significant or not. The test is actually to measure goodness-of-fit of GWR model compared to OLR model, that is to test null hypothesis that GWR and OLR model describe data variability equally well against alternative hypothesis that GWR model has better fit than OLR model does. There are several statistical procedures could be employed to perform the examination, i.e. ANOVA or F test (Brunsdon, Forteringham, and Charlton 1999; Forteringham, Brunsdon and Charlton 2002), $F1$ and $F2$ test (Leung, Mei, and Zhang 2000a). If GWR improvement is statistically significant, test for parameters variability is needed. Leung, Mei and Zhang (2000a) proposed $F3$ test which takes place in diagnosing whether the set of parameters tend to be constant or to be vary over region. Alternatively, Monte Carlo significance test procedure (Hope 1968) can also be used for such diagnostics.

In Indonesia, the application of the GWR is very limited. However, GWR has been getting implemented and developed, especially by the research group on geoinformatics. This paper presents brief review of GWR application examples in Indonesia which have been presented by the group, i.e. Saefuddin, Setiabudi and Achsani (2011) and Rahmawati (2010), to analyze poverty.

Saefuddin, Setiabudi and Achsani (2011) model poverty as a linear function of Human Development Index (HDI) of 116 districts and administrative cities in Java, Indonesia for the year of 2008 using data from The National Team for Accelerating Poverty Reduction, Office of Vice President of Republic of Indonesia (2010). Due to the existing Java condition, i.e. (1) differences of provincial and district governments, (2) distance of regions to central government, (3) regional autonomy, and (4) differences of agro-ecosystem or climate. Hence, it is reasonable to implement the GWR to analyze relationship between poverty and HDI rather than the OLR.

OLR model of poverty is firstly estimated follows simple linear form of

$$POV = \beta_0 + \beta_1 * HDI \quad (5)$$

which is describing the relationship between the numbers of poverty as a percentage of population numbers (POV) and Human Development Index (HDI). The result of analysis is presented in Table 2 with $RSS=3004.52$, $AIC_c=712.95$, $AIC=708.74$ and $R^2=47.56\%$.

All corresponding p -values of coefficients in this model indicate that intercept and HDI significantly affect poverty.

Table 2. Parameter estimates of poverty model using OLR

Variable	$\hat{\beta}$	$S(\hat{\beta})$	t	$Pr(> t)$
Intercept	104.99	8.78	11.95	<.0001
HDI	-1.27	0.12	-10.17	<.0001

(Source : Saefuddin, Setiabudi and Achسانی, 2011, pp. 281)

Since OLR model seems unsatisfied regarding to RSS and R^2 , then local models for every point in the region of interest were estimated using GWR. In selecting bandwidth of weighting function, all possible method combinations are utilized and then compared. Finally, the combination of Gaussian function and CV score approach produced an optimum bandwidth. Once, linear GWR was applied using Gaussian weighting function and the optimum bandwidth RSS decreased to 1376.66, R^2 increased to 76%, and $AICc$ and AIC decrease to 661.38 and 633.92 respectively.

To test GWR improvement, three methods of goodness-of-fits test are performed. Table 3 summaries results of ANOVA or F , $F1$ and $F2$ test. According to p -values, which were all smaller than 0.05, it could be concluded that that GWR model performed better fits than OLR model did. On the other word, GWR improvement was significant.

Table 3. Summary of GWR improvement test for poverty model

Test	df_1	df_2	F -statistic	p -value
F or ANOVA	114.00	98.24	2.18	<.0001
$F1$	100.24	114.00	0.57	0.0021
$F2$	34.31	114.00	2.77	<.0001

(Source : Saefuddin, Setiabudi and Achسانی, 2011, pp. 282)

Similar to Saefuddin, Setiabudi and Achسانی (2011), Rahmawati (2010) previously compared OLR and GWR model of per-capita expenditure per month (EXPE) of 35 villages in regency of Jember, East Java, Indonesia as a function of socio-economic indicators for the year of 2008. Initially, there were 18 predictors selected for the model. However, only three variables were included on the model as a result of variable selection. Those were distance from village to capital of regency (DIST), number of health facility in every 1000 inhabitant (HFAC) and number of beneficiary family of ASKESKIN or health assurance for poor community as percentage of number of total family (ASKES). The general form of global model is

$$EXPE = \beta_0 + \beta_1 * DIST + \beta_2 * HFAC + \beta_3 * ASKES \quad (6)$$

Table 4. Parameter estimates of expenditure model using OLR

Variable	$\hat{\beta}$	$S(\hat{\beta})$	t	$Pr(> t)$
Intercept	147313.4	80592.8	1.83	0.077
DIST	-2978.2	951.8	-3.13	0.004
HFAC	175907.0	37931.6	4.64	0.000
ASKES	-2015.1	739.2	-2.73	0.010

(Source : Rahmawati, 2010, pp. 19)

Fitting an OLR model in the form of equation (6) provides the results in Table 4. According to p -value on the table, predictors were all significantly affect per-capita expenditure. However, the model above is not quite feasible for use with the $R^2=64.7\%$ and $RSS=16.69 \times 10^{10}$.

To improve model accuracy, GWR was applied using both Gaussian and bisquare weighting function. By using Gaussian and bisquare function, RSS decrease to 7×10^{10} and 8.43×10^{10} respectively. It seems satisfactory since GWR could reduce residual sum of squares of OLR approximately up to 50%. ANOVA was also performed to examine that this model improvement is significant. Results of ANOVA were listed in Table 5. According to this table, ANOVA result for GWR models using both Gaussian and bisquare weighting function were significant, indicated by p -values. This means GWR performed better on describing variability of per-capita expenditure than OLR did.

Table 5. Summary of GWR improvement test using ANOVA for per-capita expenditure model

Weighting function	df_1	df_2	F -statistic	p -value
Gaussian	9.70	21.30	3.04	0.020
Bisquare	7.35	23.65	3.15	0.045

In addition, to investigate goodness-of-fits of model, Rahmawati (2010) also calculated Pearson product-moment correlation between observed values of per-capita expenditure to correspond fitted values of OLR and GWR. Table 7 summarized the results.

Table 6. Pearson product-moment correlation between observed values of per-capita expenditure to it fitted values

Fitted value	r	p -value
OLR model	0.80	0.00
GWR model with Gaussian function	0.92	0.00
GWR model with bisquare function	0.91	0.00

GWR allows model for one region varies to others. Variability of parameter estimates of local model are summarized in Table 7. It is obvious that parameter

estimates may be ranged from negative to positive. It means a variable could either decrease or increase per-capita expenditure depends on relative position across villages.

According to two illustrations of GWR application above, it is clear in spatial case – but not always – GWR has better performance than OLR. However, if simplicity is a priority, GWR is not to interesting due to model complexity. For governmental policy, the GWR is more preferable to optimally and appropriately allocate limited resources. Hence, regional priorities to be handled can be recommended by GWR analysis. While the OLR one is usually too broad as it does not facilitate the parameter estimates in specific locations.

Table 7. Summary statistics of parameter estimates of GWR model of per-capita expenditure

Variable	Min	Q1	Median	Q3	Max	Global
Gaussian weighting function						
Intercept	-171400	14060	42590	207500	562900	147313.4
DIST	-8046	-4768	-2745	-1030	3405	-2978.2
HFAC	-30150	88950	177400	248900	264700	175907.0
ASKES	-3033	-1927	-1735	-901	1097	-2015.1
Bisquare weighting function						
Intercept	-135000	11250	33100	166600	549800	147313.4
DIST	-7322	-4346	-2821	-987	3809	-2978.2
HFAC	-32640	81170	218300	246300	262100	175907.0
ASKES	-3469	-1920	-1740	-1170	837	-2015.1

(Source : Rahmawati, 2010, pp. 21-22)

2.3. Autoregressive Models

The research team also implemented some of the advanced spatial analysis on data assuming dependent on regional factors, i.e. autoregressive models. In this section, a general review was only addressed to Spatial Autoregressive Models (SAR), Spatial Error Models (SEM), and General Spatial Models (SGM). The difference of the three models presented in Table 8. Estimation of parameters in GSM and SAR models were obtained by maximum likelihood approach involving of the areas (Anselin 1988). While the SAR, SEM and SGM are based on the effects of spatial lag (ρ) and spatial error (λ) among areas. Properties and differences of the three spatial methods mentioned above were presented on Table 8.

These approaches are appealing in the case of spatial autocorrelation which is problematic for ordinary ordinary linear regression (OLR), assuming independently distributed errors (Lichstein *et al* 2002). For spatial data, the SAR model performs better than the OLR, that is when the null hypothesis of no spatial autocorrelation ($\rho=0$) is

rejected. In addition, the SAR model It is also performs better than the SEM in the framework of SGM encompassing both the SAR and the SEM specifications (Mairesse and Mulkay 2008).

Table 8. Spatial regression models

Model	Parameter estimator	H_0
SAR $y = \rho W y + X \beta + \varepsilon$ $\varepsilon \sim N(0, \sigma^2 I)$	$\hat{\beta} = (X'X)^{-1} X'y - (X'X)^{-1} \hat{\rho} W y$ $\hat{\rho} = (y'W'W y)^{-1} y'W'y$	$\rho = 0$
SEM $y = X \beta + u$ $u = \lambda W u + \varepsilon$ $\varepsilon \sim N(0, \sigma^2 I)$	$\hat{\sigma}^2 = \frac{(I - \lambda W)(y - X \hat{\beta})'(I - \lambda W)(y - X \hat{\beta})}{n}$ $\hat{\beta} = [(X - \hat{\lambda} W X)'(X - \hat{\lambda} W X)]^{-1} (X - \hat{\lambda} W X)'(y - \hat{\lambda} W y)$	$\lambda = 0$
SGM $y = \rho W y + X \beta + u$ $u = \lambda W u + \varepsilon$; $\varepsilon \sim N(0, \sigma^2 I)$	$\beta = X' \Omega X - 1 X' \Omega I - \lambda W y$ $\Omega = (I - \rho W)'(I - \rho W)$	$\rho = 0$ or $\lambda = 0$

There are many literatures related to autoregressive models. For examples, Lichstein *et al* (2002), Tognelli and Kelt (2004), Chun *et al* (2005), Lee (2005), Kelejian and Prunca (2008) and Mairesse and Mulkay (2008) presented application of SAR models. The example of SEM application could be found at Bhattacharjee and Jensen-Butler (2006) and Benjanuvatra (2009), while GSM at Chun *et al* (2005).

Table 9. Correlation between HCI of Poverty and Covariates under Study

Covariate	Correlation ($p < 0.05$)
Education	Negative (tend to reduce HCI)
Quality of drinking water	Negative (tend to reduce HCI)
Agricultural work	Positive (tend to increase HCI)
Non-agricultural work	Negative (tend to reduce HCI)
Literacy	Non-significant
Type of house	Negative (tend to reduce HCI)

The group compared OLR and autoregressive models on modelling poverty in Indonesia. Response variable in this study was Head Count Index (HCI) of poverty at the district level. The HCI was the percentage of population below poverty line. The explanatory variables were related to education, quality of drinking water, type of work (agriculture and non-agriculture), literacy and type of house (healthy and unhealthy house). Since the data was fitted using SAR, SEM and SGM followed equation in Table

8, the null-hypotheses were all rejected at $\alpha=5\%$, indicating that all models were statistically significant and satisfactory. Table 9 showed that the poverty indicated by the HCI was interlinked with covariates. In addition, spatial models performed better the ordinary regression. More detail explanation on the result were available in the master thesis of the team (Meilisa 2010, Yulianto 2011).

3. CONCLUDING REMARK

Poverty in Indonesia can be categorized as regionally distributed data. Therefore, spatial statistics is the mode of choice to analyze this kind of data. Geographically Weighted Regression (GWR) performed better than the ordinary regression based on statistical criteria. In addition, the model provides information at each regional model using the local specific models.

The other approaches for regional data are to implement autoregressive models, i.e. Spatial Autoregressive Models (SAR), Spatial Error Models (SEM), and General Spatial Models (SGM) models. These models provide also better conclusion where the error correlation among region are significant. Many other advanced approaches need to be explored in analysing spatial data including Spatial Generalized Linear Mixed Models and Spatial Small Area Estimation. These complex approaches have been being in the progress of research of the group.

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