Estimation of households that manages their domestic waste in not eco-friendly ways in municipal level in Indonesia using EBLUP Fay-Herriot model

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Abstract. Municipal Solid Waste (MSW) has become a major concern currently among ASEAN countries, as the amount of waste generation has increased tremendously. Indonesia generates the highest quantity of municipal waste with 64 million tonnes per year that majority generates from household waste. Each person generates 0.76 kg per day of solid waste. Accordingly, with total population about 264 million, Indonesia would generate waste 200,64 tonnes per day. Indonesia has major policies, programmes, and plans for household waste management, but household waste managements are currently not well- implemented at all domain levels, especially at local level. This study aims to estimate households that manages their domestic waste in not eco-friendly ways in municipal level in Indonesia using EBLUP Fay-Herriot model, that can accommodate small sample domain estimation. It uses household data from the 2017 National Socio-Economic Survey – Social Resilience Module from BPS (SSN17.HANSOS). This study reveals that the highest EBLUP proportion estimation of household waste management in not eco-friendly ways is by open burning (71,85%). There are municipalities with a high proportion of most ways disposing waste in not eco-friendly ways, namely Mamberamo Tengah, Yalimo, and Puncak. The EBLUP SAE approach is more efficient than the direct estimation as is indicated by the lower MSE of EBLUP SAE estimations. Estimating the proportion of households that manage their domestic waste in not eco-friendly ways needs to be done and analysed periodically in order to evaluate whether the municipal waste management programmes are well implemented in local governments.

1. Introduction
ASEAN countries have population of approximately 625 million people, which account for 8.8% of the world’s population. The population is projected to be increased to 650 million by 2020, more than half of this total population will be living in urban areas. Municipal Solid Waste (MSW) has become a major concern in the present time, as the amount of waste generation has increased tremendously due to rapid urbanization and industrialization, population growth and improved life-styles. MSW primarily comes from households, but also includes wastes from offices, hotels, shopping complexes/shops, schools, institutions, and from municipal services such as street cleaning and maintenance of recreational areas.
The per capita Municipal Solid Waste (MSW) generation in ASEAN is 1.14 kg/capita/day in 2017. In terms of total annual MSW generation, Indonesia generates the highest quantity of municipal waste with 64 million tonnes/year, followed by Thailand (26.77 million tonnes/year), Vietnam (14.66 million tonnes), Philippines (12.84 million tonnes), Singapore (7.5 million tonnes), Malaysia (0.84 million tonnes), and Lao PDR generating the lowest quantity of MSW at 0.07 million tonnes/year. Predominantly, organic waste (about or more than 50%) is the highest fraction of MSW in all ASEAN countries, except for Singapore, where organic waste accounts for only 10.5% of the total MSW. Other waste streams such as plastic, paper, and metals are also the common sight in MSW piles [9].

Like most cities in the world, population in Indonesia continues to grow every year. Problems that can arise from this are the increasing amount of municipal solid waste (MSW) production. The largest stream of municipal solid waste in Indonesia flows from households followed by traditional markets [1]. Indonesia has major policies, programmes, strategy/plan and projects in place for MSW, but these are currently not well-implemented and enforced at all district levels. This gets reflected in below average collection, recycling rate and resources recovery from MSW. Even though waste minimization and collection targets exist at the national level, they are not well adopted within the policy frameworks of local levels [3].

There are growing demands for reliable small area statistics (such as municipal level) due to implementation of government decentralization program in Indonesia, The SSN.HANSOS can contribute partly to meet this need because the SSN.HANSOS can provide statistical data on social resilience (such as social capital, political participation, domestic violence, and pro-environmental behavior). Unfortunately, the SSN.HANSOS can provide data only at the national and province levels owing to insufficient sample size. Small Area Estimation (SAE) method overcomes this problem and can produce reliable estimates for small domains, such as municipal domain. Therefore, this study aims to estimate households that manages their domestic waste in not eco-friendly ways at the municipal level in Indonesia using EBLUP Fay-Herriot model, that can accommodate small sample domain estimation. It is expected that the result of the study can be used by local government in Indonesia for identifying districts in which the households waste management need to be strengthened and monitoring improved.

Municipal Solid Waste (MSW) (also called trash) consists of everyday items such as product packaging, yard trimmings, furniture, clothing, bottles and cans, food, newspapers, appliances, electronics and batteries. Sources of MSW include residential waste (including waste from multi-family housing) and waste from commercial and institutional locations, such as businesses, schools and hospitals [10]. The Environmental Protection Agency’s (EPA) definition of MSW does not include industrial, hazardous or construction and demolition (C&D) waste. Once generated, MSW must be collected and managed.

The MSW management in Indonesia has reached its relatively sound performance during 1990-1995, where many cities were being motivated to improve their cleanliness/sanitation due to, inter alia, the existence of Adipura Award program which would be granted to any city eligible to be called as successful city. Ever since the multidimensional crises in Indonesia and the reforms entailing such crises, turning point in MSW management in Indonesia begun. The era is significantly marked by fundamental changes in political and governmental aspects, such as decentralization and local autonomy era. In line with the implementation of local autonomy policy, municipal/district governments take over the full authority and responsibility of waste management from the central/province government [2]. In order to make households waste management policy be more targeted, it is necessary to estimate the proportion of households at the municipal level who handle household waste in not eco-friendly ways.
2. Methodology

2.1. Data Source
Data source for this study is the 2017 National Socio Economic Survey-Social Resilience Module (SSN17-HANSOS). The SSN.HANSOS is conducted once in 3 years by Badan Pusat Statistik (BPS), most recently in 2017. This survey aims to provide statistical data in the areas of social resilience such as social capital, political participation, domestic violence, and pro-environmental behavior. This survey covers all districts in Indonesia. Besides the SSN17-HANSOS, this study also used the 2018 Village Potential Census (PODES18). The Village Potential Census is carried out 3 times in 10 years.

2.2. Small Area Estimation
Small Area Estimation (SAE) is one of statistical techniques for estimating subpopulation parameters whose sample size is small [6]. He defines a small area as a subset of the population with an observed variable. Hence estimation in a small area is the estimation of parameters in an area with a small number of samples (does not meet the sufficient number of samples). Estimation of small areas aims to improve the accuracy of estimators of a parameter, namely by using indirect estimation. The indirect estimation is done by borrowing strength or using additional variables in estimating parameters.

2.2.1. Empirical Best Linear Unbiased Prediction (EBLUP)
The basic assumption in developing a small area estimation model is the diversity within the small area of the response variable, which can be explained by the diversity relationship corresponding to the additional information (called as fixed effect). Another assumption is the specific diversity of small areas which cannot be explained by additional information and it is the random influence of small areas. The combination of these two assumptions forms a mixed effect model. The basic model in SAE is based on the form of a mixed linear model [6] called as Fay-Herriot models, given by:

\[ y_i = x_i^T \hat{\beta} + b_i v_i + e_i \]  

(1)

- \( y_i \) = Vector of direct estimation values based on survey design
- \( x_i \) = Matrix of auxiliary variable sized \( i \times j \)
- \( \beta \) = Vector of unknown fixed parameter sized \( j \times 1 \)
- \( v_i \) = Vector of small area random effect with assumption \( v_i \sim N(0, \sigma_v^2) \) and \( v_i = A \) and usually unknown
- \( e_i \) = Vector of unobserved random error with assumption \( e_i \sim N(0, \sigma_e^2) \) and \( \sigma_v^2 = D_i \) and usually it is assumed to be known

According to [6][7], estimate of Empirical Best Linier Unbiased Prediction (EBLUP) for \( \theta_i = x_i^T \hat{\beta} + v_i \) is of the form

\[ \hat{\theta}_i^{EBLUP} = x_i^T \hat{\beta} + \hat{\gamma}_i \left( y_i - x_i^T \hat{\beta} \right) \]  

(2)

\[ \hat{\gamma}_i = \frac{\hat{A}}{\hat{A} + D_i} \] and \( \hat{\beta} = \left( \sum_{i=1}^{m} x_i x_i^T (D_i + \hat{A}) \right)^{-1} \left( \sum_{i=1}^{m} x_i y_i \right) \)

2.2.2. Mean Squared Error of EBLUP
If \( \theta \) is a parameter and \( \hat{\theta} \) is estimate of \( \theta \), then Mean Squared Error (MSE) of \( \hat{\theta} \) can be defined as:

\[ MSE[\hat{\theta}] = \text{var}[\hat{\theta}] + \text{bias}(\hat{\theta})^2; \text{ because } 2E[(\hat{\theta} - a)] = 0 \]
Based on the definition of MSE, if the obtained \( \hat{\theta} \) is unbiased, then MSE of \( \hat{\theta} \) will be equal to variance of \( \hat{\theta} \). While standard error of \( \hat{\theta} \) is defined as positive square root of \( MSE[\hat{\theta}] \). Prasad and Rao [5] define \( MSE[\hat{\theta}_{EBLUP}] \) is of the form:

\[
MSE(\hat{\theta}_{EBLUP}) = g_{1i}(\hat{A}) + g_{2i}(\hat{A}) + 2g_{3i}(\hat{A})
\]

\[
g_{1i}(\hat{A}) = \frac{\hat{A}D_i}{\hat{A}+D_i}, \quad g_{2i}(\hat{A}) = \left(1 - \frac{\hat{A}}{\hat{A}+D_i}\right) x_i^T \left(\frac{\hat{A}+D_i}{x_i x_i^T}\right) x_i, \quad g_{3i}(\hat{A}) = \frac{2D_i^2}{m(\hat{A}+D_i)}
\]

Steps to estimate proportion of households that manage their domestic waste not in eco-friendly ways by district/municipal level are explained as follows:

a) Identifying households that manage their domestic waste not in eco-friendly ways (thrown directly into the river, burned, buried, littered)

b) Make aggregate of households that manage their domestic waste not in eco-friendly ways by municipal area (“kabupaten” and “kota”) (called as Direct Estimation)

c) Take auxiliary variables from PODES18 data which correlates with the observed variable in municipal area level. Originally there are 9 auxiliary variables:

- \( X_1 \): Number of families
- \( X_2 \): Number of poor certificate (SKTM)
- \( X_3 \): Number of traditional markets
- \( X_4 \): Number of stores
- \( X_5 \): Number of health facilities
- \( X_6 \): Number of villages with availability of health facilities
- \( X_7 \): Number of education facilities
- \( X_8 \): Number of villages with availability of public transportation
- \( X_9 \): Number of restaurants

d) Select auxiliary variables using stepwise regression

e) Calculate indirect estimation using EBLUP SAE approach

f) Comparing the estimated result of direct estimation and EBLUP SAE estimation of the proportion of households that manage their domestic waste not in eco-friendly ways

g) Comparing the MSE of direct estimation and EBLUP SAE estimation

3. Result and Discussion

After identifying how households manage their domestic waste, then we perform direct estimation. Direct estimation only relies on information from sample. Direct estimation produces estimator with good precision when the sample size is adequate. However, when the sample size is not adequate, direct estimation results in poor precision. In this study, direct estimation of the proportion of households that manages their domestic waste in not eco-friendly ways is calculated for all of municipal area (“kabupaten” and “kota”) in Indonesia. After calculating the direct estimate, then the indirect estimation is calculated using the EBLUP Fay-Herriot to obtain the proportion of households that manages their domestic waste in not eco-friendly ways (disposed directly into the river, burned, buried, littered). Before that, the selection of auxiliary variables from PODES18 data had been done based on the correlation value and the significance of the variables studied. Utilizing the stepwise regression method, four auxiliary variables were obtained to be included in the EBLUP SAE model, they are: number of poor certificate (SKTM) \( (X_2) \), Number of health facilities \( (X_5) \), Number of education facilities \( (X_7) \) and number of villages with availability of public transportation \( (X_8) \). After estimating the proportion of households that manages their domestic waste in not eco-friendly ways, both by direct estimation and the SAE EBLUP approach, then MSE of these two estimates are calculated. Fig 1 shows that MSE of Direct estimation always higher than MSE of EBLUP SAE estimation. This indicates that the EBLUP SAE estimate is more efficient than the direct estimate.
Fig 1. Comparison of MSE Direct Estimation and MSE EBLUP SAE Estimation of a. Proportion of households that dispose domestic waste directly to the river, b. Proportion of households that bury their waste, c. Proportion of households that burn their waste directly (open burning), d. Proportion of households that litter their waste.

Based on the 2017 Hansos Module Susenas data, there are four ways of handling household waste that is not eco-friendly ways, namely: i) disposing waste directly into the river, ii) disposing waste by burning (open burning), iii) disposing waste by burying, iv) disposing waste by littering. The following are statistics on the proportion of households based on how to dispose of waste:

| No. | Statistics | Minimum | Q1     | Median  | Mean    | Q3     | Maximum |
|-----|------------|---------|--------|---------|---------|--------|---------|
| i   | p_river    | 0.0026  | 0.0509 | 0.1171  | 0.1517  | 0.2146 | 0.9211  |
| ii  | p_burned   | 0.0057  | 0.6154 | 0.7917  | 0.7185  | 0.8824 | 0.9943  |
| iii | p_buried   | 0.0019  | 0.0896 | 0.1693  | 0.1899  | 0.2700 | 0.9463  |
| iv  | p_littered | 0.0002  | 0.0462 | 0.1142  | 0.1653  | 0.2375 | 0.9859  |

Based on Table 1, it can be concluded that, nationally, the highest EBLUP proportion estimation of household waste management is by burning (open burning) with an average proportion of 0.7185, means that 71.85% of households in all municipal areas in Indonesia were disposed their domestic waste by open burning. Of the four not eco-friendly ways mentioned above, the lowest minimum proportion is disposing waste by littering (0.0002), while the highest maximum proportion is open burning (0.9943).

Based on Fig 2, it can be concluded that in municipalities where the proportion of households that burning waste is high, there are also households that handle waste by dumping it into rivers, being buried and being littered. There are several municipalities with a high proportion of most ways disposing waste in not eco-friendly ways, namely Kabupaten Mamberamo Tengah, Kabupaten Yalimo, and Kabupaten Puncak, all of which are in the province of Papua. The thematic maps of four ways of handling household waste that is not eco-friendly ways can be seen in Fig 3.
As can be seen in Fig 3, it is found that disposing waste by open burning has the highest proportion compare to other not eco-friendly ways (Fig 3b).

The lowest proportion of household that manages their domestic waste not in eco-friendly ways by throwing directly into the river is Kota Tangerang, while the highest is Kabupaten Yalimo. The lowest proportion of household that manages their domestic waste not in eco-friendly ways by open burning is Kota Jakarta Pusat, while the highest is Kabupaten Rote Ndao. The lowest proportion of household that manages their domestic waste not in eco-friendly ways by burying is Kota Solok, while the highest is Kabupaten Mamberamo Tengah. The lowest proportion of household that manages their domestic waste not in eco-friendly ways by littering is Kabupaten Deli Serdang, while the highest is Kabupaten Nias Selatan. After estimating the proportion of households that manage their domestic
waste not in eco-friendly ways using EBLUP Fay-Herriot, it can be seen that it is important to eliminate the disposing of domestic waste by open burning in municipal level. Open burning activities have a negative impact especially on environment and community health. Open burning trash can spread the germs/plague. Based on PODES18 data, it can be empirically analysed the relationship between the proportion of households that manage their domestic waste not in eco-friendly ways in the municipal level with the percentage of villages affected by the plague. The results of the analysis can be seen in Fig 4.

Based on Fig 4, it can be concluded that there is a fairly high correlation between the percentage of households that burning waste and the percentage of villages that have contracted the plague at the municipal level. Uncontrolled burning of household waste creates many dangerous pollutants. According to Basic Health Research 2013, conducted by Ministry of Health, one in two Indonesian households reported burning their rubbish in the open place. These results are in line with research by [4], there is a significant relationship between open burning of household waste and upper respiratory infections experience in Indonesian children. Specifically, [4] reveals a higher proportion of open burning in an area associated with a higher risk of upper respiratory infections. Proper and environmentally friendly handling of waste by households is absolutely necessary in order to reduce the negative impact on health and the environment.

4. Conclusion
This study reveals that based on direct and indirect estimation, there are several municipalities with a high proportion of most ways disposing waste in not eco-friendly ways, namely Kabupaten Mamberamo Tengah, Kabupaten Yalimo, and Kabupaten Puncak, all of which are in the province of Papua. The highest EBLUP proportion estimation of household waste management in not eco-friendly ways is by open burning. In addition, the results of direct estimation and estimation using the EBLUP SAE approach give similar pattern. However, the estimation using the EBLUP SAE approach is more efficient than the direct estimation as is indicated by MSE of EBLUP SAE estimations are lower than MSE of direct estimations. Estimating the proportion of households that manage their domestic waste
in not eco-friendly ways needs to be done and analysed periodically in order to evaluate whether the municipal waste management programmes are well implemented in local governments. Solid Waste Management Act 18/2008 is expected to bring major changes and new challenges in waste management in Indonesia, which will serve as the umbrella for sound MSW managements in Indonesia, strengthened by issuing MSW Government Regulation No.12/2012 and other regulations which are issued by Central Government and Local Governments.

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