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Quantification of Residential Land Use Characteristics from an Impact Generation Potential Perspective

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Abstract

United Nation's World urbanization prospects Report 2001, projected that the proportion of urban population in the world will touch 70% by 2050. In 2012, according to the World Bank data catalogue, 53% of the world population can be categorized as urban population, people living in urban areas as defined by respective national statistical offices. Increasing trend of this urbanization has made the residential land use a major shareholder in urban land uses. Residential land use predominantly consist of buildings used or constructed or adopted to be used wholly for human habitation and also include garages, and other out-houses necessary for the normal use of the building as a residence. There are systems/methods like Environmental Impact Assessment in place to check on the impacts of individual buildings/projects on environment. However a method/system to check the environmental implications of specific/critical land uses from a holistic viewpoint is totally missing. To conduct such a check it is mandatory to know basic traits of the land use under consideration. This paper fundamentally discusses on how to capture the innate characteristics of residential land use in an area and thereby its impact generation capacity and to express it as a site specific index. For this an expert survey was performed to integrate the various characteristics of residential land use in an urban area of a large city. The study was conducted in an Indian Urban context where there is multiplicity in scale of residential development and socioeconomic back ground of people. The expert group's organized inputs are gathered, compared and composed in this regard and the results are presented and communicated.

Keywords: Analytical Hierarchy Process, Environmental Impacts, Index Generation, Land Use Characteristic's

1. Introduction

Percentage share of urban population in the world will touch 70% by 2050 according to United Nation's World urbanization prospects Report 2001[1] and as per the UN-HABITAT Annual report 2005, it is estimated that 93% of the urban growth will occur in Asia and Africa and to a lesser extent in Latin America and Caribbean[2]. It is predicted that along with this population increase there is going to be a dramatic growth in the extent of individual urban centres too[3]. Increasing trend of this urbanization has made residential land use a major shareholder in urban land uses. Residential land use calls for the requirement of other facilities like physical and social infrastructure to support it. Planning these facilities for the comfort of human beings has eventually put urban environment under pressure due to its ever-increasing rate of resource extraction, utilization, waste generation etc. Even though there are methods like Environmental Impact Assessment in place to check on the impacts of individual buildings/projects on environment, a method/system to check the environmental propositions of land

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uses from an all-inclusive perspective is completely missing. To examine these implications it is required to know basic characteristics of the land use under consideration. This paper primarily converses on how to capture the integral characteristics of residential land use in an area and thereby its impact generation capacity and to express it as a location specific index. For this an expert survey was conducted to elicit required information to formulate the same for an urban area of a large city.

2. Research Background

According to 2001 census in India, 285 million people lived in urban areas and anticipated escalation to 550 million by the year 2021 and 800 million by 2041[4]. Upward trend of this urban population and the related extent in urban area has made residential land use a major stakeholder in all urban land use plans. Urban and Rural Development Plan Formulation and Implementation (URDPFI) guidelines issued by Ministry of Urban Affairs suggests that 40% of the developed land in a metro city should be apportioned for residential activity, while this share should be 50% in case of small urban centers[5]. According to zoning regulations stipulated by UDPFI guidelines, Residential land use zones primarily consist of buildings used or constructed or adopted to be used wholly for human habitation and include garages, and other out-houses necessary for the normal use of the building as a residence. The other buildings with uses which are indispensible for sustaining residential activities are also permitted in this zone. Since residential population is the basis for provision of resources and infrastructure, residential land use assumes a dictating position in master planning process. There are available methods to check the impacts of individual projects but to check the environmental impacts of residential land use holistically is missing.

3. Methodology

A detailed methodology for identifying residential land use parameters that will capture its characteristics is described below. Main objective of this study is to detect the critical parameters of the residential landuse that can be used to create an index which will capture the impact generation potential of residential activities in an area under consideration. The fundamental hypotheses used for the development of this index which bring forth the essential understanding about the characteristics of residential land use with respect to its impact generation potential are:

- Urban environment is composed of modules such as natural resources, transportation, social and physical infrastructure, Solid waste generation and management, Biodiversity and Local economy.
- A land use parameter would qualify to be incorporated in the index if it has considerable/major influence on more than four urban environment components.
- Index as proposed will integrate the urban environment features and the residential land use parameters in a location specific manner.

Residential land use parameters are selected such that they are common factors in generating impacts on the heterogeneous modules of urban environment as stated above. The heterogeneous nature of the various sectors on which urban planning depend on resulted in an interdisciplinary research domain. In a developing country like India, availability of structured data for such a research is a major concern and for this type of research a Questionnaire Survey of Experts (QSE) can be employed to draw information from experts in required fields[6]. Residential land use parameters obtained from literature survey was then processed through organized interviews using a random sample of experts from the above sectors of urban environment.

3.1 Questionnaire Instrument Construction

A questionnaire instrument was developed to extract coordinated information on critical parameters of the residential landuse based on its impact generation potential. This instrument was prepared with the following objectives.

- To establish the basic premises of residential land use characteristics.
- Consolidate various dimensions of residential land use impacts on urban environment modules.
- Collect information on the critical parameters of residential land use and assess their relative weightage.

The questionnaire was created with an assemblage of question types such as equal interval ranking questions to assess weightage of the set of parameters under consideration and these were open ended questions to factor

in the freedom for experts to give their choices/wisdoms, equal interval rating questions and pair wise comparison questions were also included to calculate relative weightage among parameters. Questionnaire instrument was verified for its rationality by performing a pilot survey and refined including their suggestions. The questionnaire instrument was also checked using Cronbach Alpha Test for its consistency and ensured a reliability coefficient (alpha) range of 0.78 to 0.90 for all questions.

Analytical Hierarchy Process (AHP) is used in the questionnaire analysis for resolving multi-criteria decision making as it offers a procedure to relate complex systems qualitatively and quantitatively among the varied expert group. The standard 9 point AHP scale is used for pair wise comparison questions[7]. Important stages followed in AHP are:

- Establishing an order of critical residential land use parameter.
- Collect information through a pair wise comparison survey from the experts based on their preferences.
- Analysis of the results and the consistency check.
- Combine the results to obtain a set of ratings of critical residential land use parameters.

3.2 Selection of Experts

Experts for questionnaire survey were selected based on the heterogeneous modules of urban environment on which residential land use can have impacts due to its activities. Expert survey population consists of all the experts who work primarily at a decision making positions in any of the identified urban environment modules in south India as south India holds more than twenty large cities out of the total sixty large cities in India[8]. There are six distinct set of experts who can give their expert judgment on not less than two of the eight unban environment modules. Expert categories consists of people from Urban planning who can give inputs on generic impact of residential land use on all urban environment modules by virtue of their expertise, infrastructure planning experts will provide input on three modules of urban environment namely traffic and transportation, urban infrastructure and waste management, Water resources experts can provide responses on natural resources, biodiversity and urban infrastructure modules of urban environment, Environmental Management Experts will be able to contribute on waste management and biodiversity module of urban environment, Urban geography experts will be able to give expert opinion on natural resources and biodiversity modules of the urban environment, Environmentalists will be able to give expertise on Biodiversity, local economy and waste management module of urban environment from a holistic perspective. There are about 800 experts are from the four states of South India forms the population for the expert questionnaire survey. A sample size of 93 experts was estimated with 95% confidence level and 10% confidence interval. Sampling error types was also suitably considered while assessing the sample size.

3.3 Questionnaire Survey Data Analysis

Main goal of this survey was to compute the relative weightage of residential land use parameters that will capture the characteristics of a residential area from the impact generation ability on account of its activities. This was calculated from both rank order question analysis and AHP based pair wise comparison questions. In case of equal interval ranking questions relative weightage was calculated using the following method. Assume that there are 'n' experts ranking 'a' options with ranks '1 to b', where '(b ≤ a)'. A system of scoring was adopted by assigning the reciprocals of ranks '(1/b)' in to scores '(s)' and 'nxy' represented number of experts assigned rank 'y' (where 'y' = 1 to b) to option 'x' (where 'x' = 1 to a). The total score for option x is calculated as $\sum_{y=1}^{b} N_y S_y$ and the total score for all the options is calculated as $\sum_{x=1}^{a}\sum_{y=1}^{b} NxySxy$ $\sum_{x=1}^{a}\sum_{y=1}^{b} NxySxy$. Then the weightage of each option can be worked out as:

$$\sum_{y=1}^{b} NySy \,/\, \sum_{x=1}^{a}\sum_{y}^{b} NxySxy$$

Through the questionnaire survey and its analysis, a set of critical parameters of residential land use which is having a major role in causing impacts on the urban environment modules was identified. Major parameters identified to encapsulate the residential land use impacts on urban environment are residential scale and the house hold income of the residents. Residential scale means the type of residence and the number of families residing in the building. This is further divided in to three categories such as:

- Detached residential buildings with single family residing in it (Villa type).
- Low rise apartments with multiple families dwelling in (height of the building is restricted to Less than ground + three floors).

- High rise apartments with multiple number of families staying in it (height of the building will be more than four floors).

Residential households are divided in to four categories with respect to their household income such as:

- High Income Group (monthly household income is more than Rs. 50000.00).
- Middle Income Group (Monthly household income Rs. 15,000-50,000).
- Low Income Group (Monthly household income Rs. 3,300 -15,000).
- Economically Weaker Section (Monthly household income is less than Rs. 3,300).

Pair wise comparison of AHP questions analysis was conducted as detailed. A pair wise comparison reciprocal matrix[9] of opinions was constructed and by solving this matrix using Eigen vector method relative importance of opinions was derived. In addition a consistency index is calculated to check the matrix consistency. When the Eigen value is equal to the dimension of the matrix, then the matrix can be considered consistent. But if it is more than the dimension of the matrix then the matrix is said to be inconsistent[10]. Individual experts' consistency in giving opinion should also need to be measured and compared to an indicative consistency known as Random consistency index[11]. If Consistency Ratio is less than or equal to 0.1 the inconsistency is usually acceptable and there are also many researchers who have accepted CR values up to 0.2[12].

By conducting the AHP analysis using the above cited method, relative weightage of the categories of the characteristic parameters of residential land uses in impact generation were quantified. Relative weightages derived through AHP analysis for the household income group based on its impact creation capability is given in following Table 1.

Relative weightages of residential scale present in the area were also derived through AHP Analysis and is explained in the following Table 2.

In the above analysis consistency ratio for the combined expert group was 0.045 and 0.04 respectively for household income group and residential scale respectively which are very well within the allowable limit of between 0 and 0.1. Using these relative weightages and the proportion of characteristics of households present in the identified residential area, a location specific coefficient to summarize the impact generation potential of residential land use activities called *"Coefficient of residential land use characteristics"* is worked out as detailed.

Table 1. Relative weightages of household income group

Household income Group	Monthly hold income	Relative weightage
HIG - High Income group	> Rs. 50000.00	0.334
MIG – Middle income group	Rs. 15,000-50,000	0.183
LIG – Low Income Group	Rs. 3,300 -15,000	0.173
EWS – Economically weaker section	< Rs. 3,300	0.310

Table 2. Relative weightages of household income group

Residential Scale	Relative weightage
Detached single family units (villa type)	0.190
Low rise multifamily units (up to G + 3floors)	0.260
High rise multifamily units (> 4 floors)	0.550

3.4 Coefficient of Residential Land use Characteristics

Coefficient of residential land use characteristics (C_{rlc}) is an index to capture the impact origination capability of residential land use activities on the urban environment from an urban planning perspective. This is conceptualized and exemplified to measure the capabilities of the residential land use activities in impact origination on urban environment in a large city/urban context. This is also meant for use in a selection of explicit or implicit urban environment contexts as listed below:

- To summarize the existing condition of the residential land use activities of that area.
- A measure that can be used to compare the present and future residential land use status in accordance with its activities.
- It can be used as a tool to envisage the pressure/potentials of residential land use policies on the urban environment.

Essentially, Coefficient of residential land use characteristic is assumed to be location specific as the basic characteristic parameter combinations of residential areas are different for different locations. C_{rlc} is calculated as the sum of two distinctive parts. First part is the product of relative weightage as derived through the AHP analysis of the expert questionnaire survey for the household income categories and the proportional share of the income categories residing in the residential area under consideration. Second part is the product of relative weightage as derived through the AHP analysis of the expert questionnaire survey for the residential scale and the proportional share of the scale categories existing in the residential area under consideration. This can be expressed as:

$$C_{rlc} = \sum_{t=1}^{n} S_i \times P_i + \sum_{j=1}^{n} Ij \times Q_j \quad (1)$$

Where 'S_i' is the relative weightage of the residential scale as derived through AHP analysis of expert questionnaire survey, 'P_i' is the proportion of the corresponding residential scale category available in the area, '*i*' is the available residential scale category in the area, like high rise multifamily units, low rise multifamily units etc. 'I_j' is the relative weightage of the household income as derived through expert questionnaire survey, 'Q_j' is the proportion of the corresponding Income group available in the area, '*j*' is the available income groups in the area, like high income group, low income group etc.

Coefficient of residential land use characteristics has been tested and validated by checking its trend in real life situations. Waste generation which is the most impacted sector of the urban environment module is selected to validate this coefficient. The coefficient was tested in selected wards of three cities in south India namely Thiruvananthapuram, Kozhikode and Coimbatore. Two wards where the residential land use was predominant were selected for validation purpose. An optimal sample size was arrived upon based on the average number of households in the identified cities. As per 2011 census the average number of households in a ward in the identified cities is 2000. At 99% confidence level and 10% confidence interval, the appropriate sample size of households was taken as about 154/ward. Such two wards where residential land use dominated were surveyed per city and the results were used for calculating the coefficient of residential land use characteristics of the ward and the corresponding waste generation rate per household. Results of this are discussed in detail in the following section.

4. Results and Discussions

Fundamentally coefficient of residential land use characteristics of a residential area in an urban context should reflect its capability in affecting the functioning of urban systems, management of urban resources and requirement of infrastructure services. Using Equation (1), C_{rlc} for all the selected wards of the identified cities were computed and tabulated in Table 3.

Table 3. Coefficient of residential land use characteristics (Crlc) of selected wards

City	Ward No	C_{rlc}
Thiruvananthapuram	22	0.420
	23	0.542
Coimbatore	67	0.488
	56	0.475
Kozhikode	5	0.441
	32	0.456

It may be noted that the highest and lowest C_{rlc} is in Thiruvananthapuram with more than 25% variation between the wards. The other two cities do not have significant variation in C_{rlc} values. Ideally C_{rlc} should vary between 0.3 and 0.9. In the case of identified wards in the selected three cities the value concentrates around 0.4 to 0.5. Concentration of middle income group families in the surveyed areas would have contributed to this scenario. Similar C_{rlc} also suggests that urban residential population have similar characteristics irrespective of their locations such as small/medium towns and large towns. Conceptually higher C_{rlc} should yield higher impacts on urban environment modules. A check for such performance is required to prove this hypothesis. Consequently it is essential to select a best suited urban environment module for this process. Relative weightages of the urban environment modules impacted by residential land use activities as identified through questionnaire suggests that waste management module is the most critically impacted one among the seven urban environment modules as stated in the premises. The following table (Table 4.) explains the relative weightages of urban environment modules.

Hence waste generation was selected to use as a common indicator to check its variation with respect to the C_{rlc} values in the selected areas. For this purpose average

Table 4. Relative weightages of urban environment modules

Urban environment modules	Relative weightage
Natural Resources	0.12
Waste generation	0.34
Biodiversity	0.06
Transportation	0.22
Physical Infrastructure	0.13
Social Infrastructure	0.09
Local Economy	0.04

waste generated per house hold per day of the same sample of the study area was collected which is given in the Table 5.

It can be observed from the data that the average per capita waste generation in both categories of waste is comparable in all three cities irrespective of its inherent qualities/properties. Waste generation per household is varying due to variations in average household size in the selected wards. To check the validity of C_{rlc}, it is analyzed with the waste generation pattern of the respective wards. The following Figures 1 and 2 shows the quantity of bio degradable and non bio degradable waste generation per household and the respective C_{rlc}'s of the identified wards.

It can be observed that in wards where there is a higher C_{rlc} their bio degradable and non bio degradable waste generation is also more. A deviation can be seen in the case of ward 56 of Coimbatore city which is due to smaller average house hold size compared to other wards. Identification of an empirical relationship is not possible at this stage as this is checked with a limited number of wards in identified cities. However it can be claimed that higher C_{rlc} of the residential area will result in higher impact on the urban environment modules.

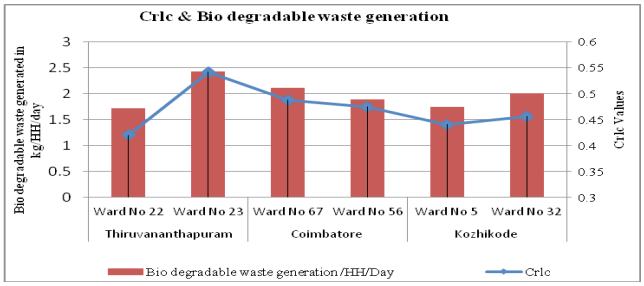

Figure 1. C_{rlc} and bio degradable waste generation.

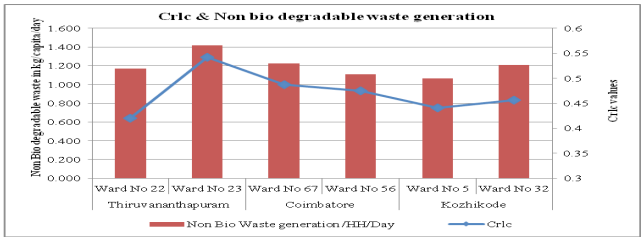

Figure 2. C_{rlc} and non bio degradable waste generation.

5. Conclusion

This paper elaborates a methodology to evaluate the major residential land use characteristics that influence the extent of impacts on the identified urban environment modules and as part of a system to quantify the land use impacts. The proposed coefficient of residential land use characteristics can be further refined for capturing impacts on all other identified urban environment modules and then make it robust. The coefficient suggested here broadly aligning with the trend of waste generation in the urban contexts studied. Even though most of the standard procedures are followed to conceptualize C_{rlc} further refinements are possible in this like validating the performance of the coefficient based on the extent of impacts in other urban environment modules as well. This

Table 5. Average waste generated per household per day

City	Ward No	Average bio degradable waste generated kg/capita/day	Average bio degradable Waste generated kg/HH/day	Average Non bio degradable waste generated kg/capita/day	Average Non bio degradable Waste generated in kg/HH/day
Thiruvananthapuram	22	0.442	1.72	0.300	1.170
	23	0.487	2.43	0.283	1.417
Coimbatore	67	0.468	2.10	0.272	1.223
	56	0.460	1.88	0.270	1.107
Kozhikode	5	0.447	1.74	0.288	1.067
	32	0.457	2.01	0.275	1.210

can be planned as an extension of this work and that will strengthen this concept. An index that can capture the essence of the heterogeneous nature of land use's innate activities will help in urban planning and related decision making regime such as resource allocation, infrastructure planning etc. This index can also help in land use allocation in the master planning process as this will give an idea of the carrying capacity of an area to contain residential land use.

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