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A GIS Based Walkability Measurement within the Built Environment of Khulna City, Bangladesh

Sourav Bhadra[*]
A. K. M. Tanbir Sazid[**]
Md. Esraz-Ul-Zannat[***]

Abstract

Walking has become an intense topic in the field of urban planning, transportation planning and urban health sector. To evaluate the walking pattern of a city, first walkability is needed to be assessed. The effects of built environment on walking has been drawn out in separate walkability assessment studies worldwide. But walkability assessment in the context of a developing country is not too common, especially in Bangladesh it is unprecedented. This study proposesa method of developing walkability index model for Khulna City. The study can disseminate walkability scores for each ward and can find out the hierarchy of different wards according to their ability of promoting more walking. The walkability index equation has been generated comparing two model diagnostics i.e. Ordinary Least Squares (OLS) and Geographically Weighted Regression (GWR). By comparing OLS and GWR, the most suitable model was found from GWR. By using this equation, scores of walkability index for each ward was calculated and three levels of walkability was found i.e. High, Medium and Low. By analyzing residents' perception on reasons of walking, safety of walking, obstacles for walking and satisfactory level of footpaths, a different score and rank was calculated. The spearman's rank correlation coefficient was found significant (ρ=0.81) which indicates that the results found from walkability model index is good.

Introduction

Walking is one of the most common forms of physical activity which improves residents' quality of life by providing inexpensive transportation options. With so many associated benefits such as reducing air pollution, traffic congestion, fuel crisis, slowing down the rate of obesity and other health related problems, walking has become a hot cake worldwide for research. The function and development of modern cities is highly dependent on the availability of efficient transportation facilities which support walking (Schreck et al., 2013:354). But in the last 50 years, planning practice has been primarily concerned with the automobile and motorists' comfort and convenience rather than the pedestrians (Untermann and Lewicki, 1984:238). This situation occurred due to the dominant role of automobile as a rapid and fast transportation mode. As a result, cities and neighborhoods are becoming stable from promoting walk friendly environment. Walkability is the ability of an area or neighborhood or community for promoting walk

[*] Junior GIS Analyst, ICT-GIS Division, Institute of Water Modelling (IWM), Dhaka-1206, Email: sbhadra019@gmail.com

[**] Junior Urban Planner, Global Survey Consultants (GSC), Baitulaman Housing, Adabor, Dhaka-1207, Email: tsazid@gmail.com

[***] Assistant Professor, Department of Urban and Regional Planning, Khulna University of Engineering & Technology (KUET), Khulna-9203, Email: esrazuz@gmail.com

friendly environment. It describes the capacity of built environments to support walking for multiple purposes including utilitarian purposes such as walking for transport. Active transport may contribute to environmental health, as well as to a population's total daily physical activity (Sallis et al., 2004:249).

As being the 3rd largest city of Bangladesh, Khulna is facing increased population growth and consequently the rapid development of urban built up area day by day. Khulna city has peculiarities in its transportation sector, which is, the great dependence on non-motorized slow moving vehicles, high degree of pedestrian movement and lack of proper road network suitable for the transportation services all combined together possess a different problem for the city (Hossain, nd:6). Planning has been primarily concerned with the comfort and convenience of the automobiles and motorists. Walking has now become a secondary consideration in transportation and urban planning. As a result, city dwellers are facing such problems as delay, congestion, discomfort, poor or no accessibility, poor visibility and accident danger.

To improve the quality and efficiency of pedestrian environment of a city, at first the condition of the built environment affecting walking behavior is needed to be assessed. This can be done by measuring neighborhood walkability first. The measurement of walkability incorporates a number of methods and approaches. Transportation researchers, urban planners and other specialists has been broadly measuring walkability through two approaches i.e. subjective approach and objective approach (Park, nd:28). Subjective approach incorporates the qualitative analysis of walkability (e.g. peoples' perception for walking, sense of safety and security, aesthetics of footpaths etc.). Objective approach includes the quantitative analysis of various attributes affecting walking behavior e.g. dwelling density, intersection density, land use mix, retail floor area etc. (Lotfi and Koohsari, 2011:402) In this study the walkability of Khulna City has been calculated using objective approach and validated using subjective approach. Various applications of GIS have been used to develop and validate the model. The study provides a general walkabilityindex model for Khulna city and scores as well as hierarchy of different wards according to the walkability score calculated from the derived model. The model results were validated using the peoples' perception found from questionnaire survey.

Literature Review

Walkability is an important term in the context of transportation engineering & planning, urban planning and health disciplines. So the definition of walkability has to support all the activities of these professional disciplines. Defining walkability is not an easy task because of it's influence in various sectors. However various researchers, professionals and practitioners have been using and giving different kind of walkability definition. P. T. Seilo defines walkability as "… a measure of the urban form and the quality and availability of pedestrian infrastructure contained within a defined area. Pedestrian infrastructure includes amenities developed to promote pedestrian efficiency and safety such as sidewalks, trails and pedestrian bridges…" in his book entitled "Walkability and Urban Form: A GIS-based Analysis of Nodal Development Areas in the Eugene-Springfield Metropolitan Area" (Seilo, 2004:154). According to Mayne et al. "Walkability describes the capacity of built environments to support walking for multiple purposes including utilitarian purposes such as walking for transport. Active transport may contribute to environmental health, as well as to a population's total daily physical activity." They emphasized on built environment attributes which promote more walking (Mayne, et al., 2013:2).

The term walkability is consisted of two separate words 'walk' and 'ability'. In the Oxford University Press Dictionary 'walking' is defined as "The action of moving or travelling at a regular and fairly slow pace by lifting and setting down each foot in turn so that one of the feet is always on the ground…" and 'ability' means "the fact that somebody/something is able to do something". Thus walkability of a place must include that something should promote walking or because of something that place is walking friendly. It is also true that the word 'something' is very confusing. But the majority of examples refer the word 'something' to various urban built environments although other examples have been found that refer to people i.e. the ability of walking of an individual or walking community. In this study walkability is defined as the ability of an area or community or neighborhood to promote walking, based on its built environmental attributes. More walkable area means that more number of walking is occurring in that area for its present urban built environment, in short, more people are walking in that area.

During the last decade there has been a considerable amount of studies in the literature of public health, transportation, and urban design examining the relationship between the built environment and physical activity, specially walking. These studies confirm the strong correlation among access to parks, recreational, and exercise facilities (Sallis et al. 1990:181; Duncan et al. 2005:9); access to shopping (Michael et al. 2006:303; Pikora et al. 2006:710); sidewalk condition (De Bourdeaudhuij et al. 2003:84); residential density (Saelens et al. 2003:1554; Frank et al. 2005:117); land-use mix (Frank et al. 2005:117; Owen et al. 2007:388); neighborhood aesthetics (Ball et al. 2001:435; Humpel et al. 2002:189); street connectivity (Li et al. 2005:558; Owen et al. 2007:388); and walking. Nevertheless, strong relations among some aspects of the built environment such as proximity to parks (Lackey and Kaczynski 2009:2); neo-traditional neighborhood features alone (e.g., sidewalks, front porches, and small set-back distances) (Wells and Yang 2008:314); and walking have been questioned by some researchers.

In this study, total seven criteria have been selected as built environmental attributes affecting walking behavior. The relationship between the criteria and walking as well as their definition is described below.

Net Intersection Density (NID)

Net intersection density is the ratio of the intersection numbers and neighborhood areas. Higher intersection densities are correlated with increased network connectivity, thus providing people with a greater choice of potential routes, easier access to major roads where public transport may be an option and shorter times to get to destinations due to having more direct routes available (Dobesova and Krivka, 2012:184).

Land Use Mix (LUM)

The measurement of land use mix (the diversity of uses and accessibility) can be measured using an entropy score, which calculates the degree to which different land uses are scattered within an area (Leslie et al, 2007:114). People who live near multiple and diverse retail opportunities tend to make more frequent, more specialized and shorter shopping trips, many by walking. The more varied the land use mix, the more varied and interesting the built-form, then the more conducive it is to walk to various destinations (Dobesova and Krivka, 2012:185)

An entropy equation acquired from previous similar walkability studies can be used to calculate the land use mix (Frank, et al., 2010:926).

$$Lnad\ Use\ Mix\ (LUM) = -\frac{\sum_k (p_k \ln p_k)}{\ln N}$$

Where,

k = the category of land use,

p = the proportion of the land area devoted to a specific land use,

N = the number of land use categories

The entropy equation results in a score of 0-1, with 0 representing homogeneity (all land uses are of a single type) and 1 representing heterogeneity (the developed area is evenly distributed among all land use categories).

Net Retail Floor Area Density (NRFAD)

The floor area of buildings which are devoted to retail purposes within a specified area. Generally, it is seen that people walk for retail shopping most. So the greater retail floor area density represents more walking. (Frank, et al., 2010:926)

Net Roadside Vegetation Area Density (NRVAD)

Net Roadside Vegetation Area is the ratio of net roadside vegetation and the total area of the neighborhoods. The value is always below 1 and greater than zero. Walking is directly depended to roadside vegetation. More value indicates the more vegetation along with the roadside which encourages the walking.

Net Flood Free Area Density (NFFAD)

It is an opposite representation of water inundated area density. Walking is discouraged if the area is frequently facing water logging problem. This criterion represents the density of flood free area within a specific neighborhood. More the density, better the walking.

Net Educational Institutional Floor Area Density (NEIFAD)

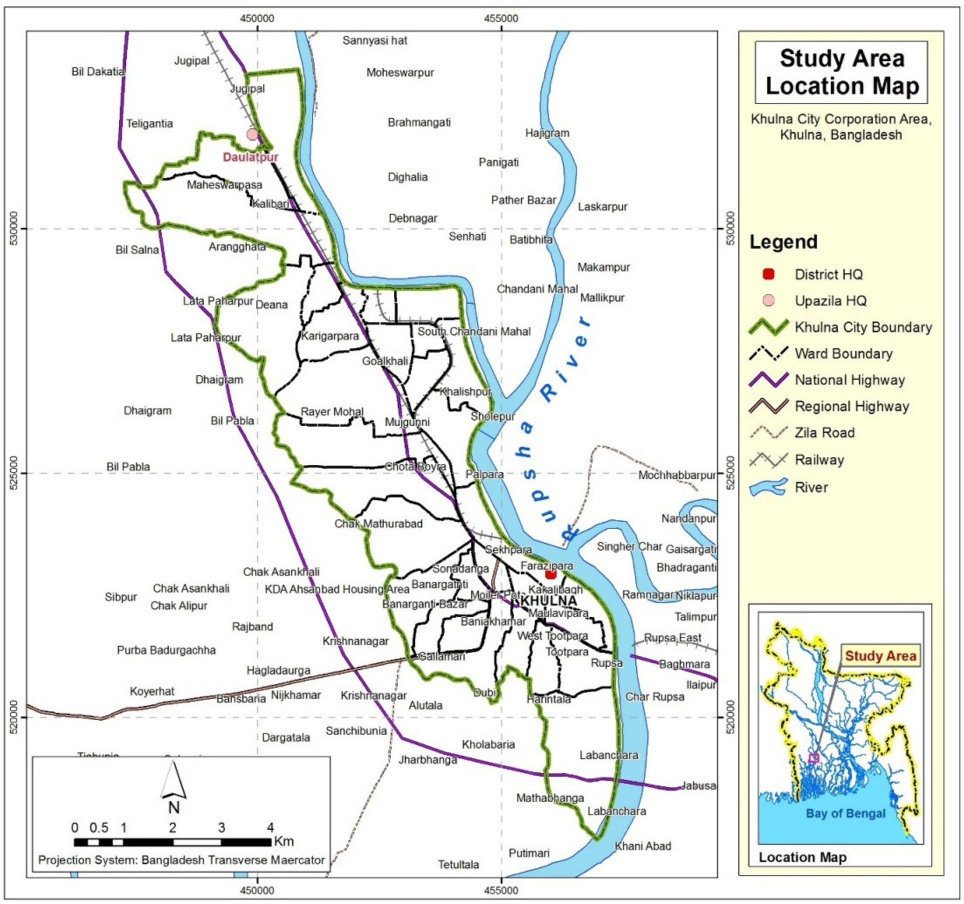
It measures the influences of educational institutions (school, college) over walkability in the neighborhoods. It is the ratio of total floor area of educational institutions and the area of the neighborhoods. Higher ratio indicates that the maximum area of that neighborhood is occupied by more people including students, their guardians, and different retail shops inside and outside of the institution. Moreover, the open spaces among the institutions also encourages the walking.

Net Footpath Area Density (NFAD)

Net footpath area is directly related with the walking practice. It is the ratio of total footpath area and the area of the neighborhoods. High ratio indicates the proper infrastructural support for walking among the neighborhoods. More footpath also encourages walking practice and increase the satisfaction level of the residents in the neighborhoods.

Study Area

Khulna is located in southwestern Bangladesh between 21.38' and 23.1 north latitude and 88.58 east longitude and is 12 ft above mean sea level. It covers a total area of 59.57 km², while the district itself is about 4394.46 km². It lies south of Jessore and Narail, East of Satkhira, West of Bagerhat and North of the Bay of Bengal. It is part of the largest delta in the world. In the southern part of the delta lies the Sundarban, the world's largest mangrove forest. The city of Khulna is in the northern part of the district, and is mainly an expansion of trade centers close to the Rupsha and Bhairab rivers. The Mayur River forms the western boundary of the metropolitan area. Figure: 1 shows the location of the study area.



Source: Compiled from DAP, 2010

Fig. 1: Location of the study area

Methodology

The study incorporates a large set of spatial datasets which have been collected from DAP of Khulna City. All the built environmental criteria have been measured from this spatial dataset in ArcGIS environment. A questionnaire survey has been done to find out the walking time or frequency per week for each respondents. Total 200 samples were selected for questionnaire survey. A buffer area of 200m around their household location has been created to measure each criterion under this area. So, each built environmental criteria were calculated for each buffer area of 200 samples. To generate the walkability index model equation for Khulna City, two regression analysis has been done i.e. Ordinary Least Square (OLS) and Geographically Weighted Regression (GWR). Total 70% data has been used in this analysis. Other 30% sample data were used to see the accuracy of the best fitted model. By comparing the two models according to the values of some criteria i.e. Multiple R-Squared, Adjusted R-Squared, Akaike's Information Criterion (AICc) and Global Moran's I value.

From the generated walkability index equation, walkability index score for each ward of Khulna City was calculated and the hierarchy of the wards in the context of walkability score was found. In the questionnaire survey respondents were asked about the safety of walking, obstacles in walking and the satisfactory level of the condition and availability of footpaths in their neighborhood. From these variables, an average score for each surveyed ward was calculated and another hierarchy of wards in the context of walking behavior was found. Then a spearman's rank correlation coefficient for these two types of ranks was calculated to find out the validity of walkability index model equation.

Data Analysis

The required spatial datasets for calculating the seven built environmental criteria were prepared in GIS and each criteria were calculated separately for both buffer areas and wards. Then the walkability index model equation was derived from two regression analysis i.e. OLS and GWR.

Exploring the Data

The 70% sample data were explored first to see if the variables were statistically significant or not. By performing incremental spatial autocorrelation and spatial weights matrix generation, exploratory regression was done. The results of exploratory regression are shown in Table 1. This table describes the percentage of significance of the variables as well as their percentage of negative or positive possibility under a certain number of criteria (i.e.R^2 value, Coefficient P-value, Variance Inflation Factor, Jarque-Bara P-value, Spatial Autocorrelation P-value).

Table 1: Variable significance summary of exploratory regression

Variable	Percentage of Significance	Negative Percentage	Positive Percentage
LUM	100.00	0.00	100.00
NFFAD	100.00	0.00	100.00
NFAD	93.75	0.00	100.00
NRFAD	75.00	25.00	75.00
NRVAD	75.00	0.00	100.00
NID	40.62	3.12	96.88
NEIFAD	39.06	51.56	48.44

Source: Author, 2015

From the exploratory regression analysis, it is seen that every variable returned good significance value except for NID and NEIFAD (<50%). But all of them were considered for OLS and GWR because of their practical importance.

Model Development

By exploring the data, it is clear that all of the selected variables are showing good percentage of significance. So in the OLS model, all of the explanatory or dependent variables were considered along with the walking time per week as dependent variable. The results of OLS model show a summary of coefficient, standard error, t-statistic, p-value, robust p-value and VIF for all of the variables and intercept. Table 2 shows the summary of OLS results.

Table 2: Summary of OLS results

Variable	Coefficient	Standard Error	t-Statistic	P-value	VIF
Intercept	-393.91	32.948545	-11.95532	0.000000*	----------
NID	1.23	0.508165	2.412431	0.017212*	1.164419
LUM	764.46	47.326133	16.153001	0.000000*	1.586577
NRFAD	0.002488	0.001040	2.393109	0.018105*	1.708343
NFFAD	0.000393	0.000109	3.605356	0.000449*	1.183276
Variable	Coefficient	Standard Error	t-Statistic	P-value	VIF
NEIFAD	-0.021307	0.005452	-3.908304	0.000154*	1.177212
NRVAD	0.008798	0.000923	9.534579	0.000000*	1.540258
NFAD	0.024670	0.005987	4.120254	0.000071*	1.148702

* indicates the statistically significant variables(source: Author, 2015)

From the summary, all the P-values for each variable are found statistically significant ($p<0.05$). The Variance Inflation Factor (VIF) is also found significant (<7.5) for all of the variables, which indicates that there is no redundancy among explanatory variables.

Geographically Weighted Regression model is a local form of linear regression used to model spatially varying relationships. In this model the dependent variable was selected as walking time per week. The independent or explanatory variables were NID, LUM, NRFAD, NFFAD, NRVAD, NEIFAD and NFAD. The kernel type was selected as Adaptive as it represents the spatial context is a function of a specified number of neighbors. Where feature distribution is dense, the spatial context is smaller; where feature distribution is sparse, the spatial context is larger. The bandwidth method specifies how the extent of the kernel should be determined. In this analysis the extent of the kernel was determined by a fixed number of neighbors which was 30. Table 3 represents the average coefficient and standard error found from this model.

Table 3: Average coefficient and standard error for each variables and intercept

Variables	Coefficient	Standard Error
Intercept	-356.3326274	129.7888995
NID	0.013487709	308.0329246
LUM	776.5676204	23418.59813
NRFA	0.001385195	0.924858913
NFFA	0.00012549	0.075914053
NEIFA	-0.026750371	3.018878715
NRVA	0.00699798	0.571712715
NFA	0.033923633	3.329130722

Source: Author, 2015

The two models were compared to make a decision about which model is the best fitted model. To compare the models, a number of criteria were selected i.e. Multiple R-Squared, Akaike's Information Criterion and Global Moran's I value. Table 4 shows the comparison of the two models.

Table 4: Comparison of OLS and GWR models

Comparable criteria	OLS	GWR
Multiple R-Squared	0.789953	0.950440039
Adjusted R-Squared	0.778814	0.895245833
Akaike's Information Criterion	1506.291842	305.0201262
Global Moran's I value	0.028725	-0.187300

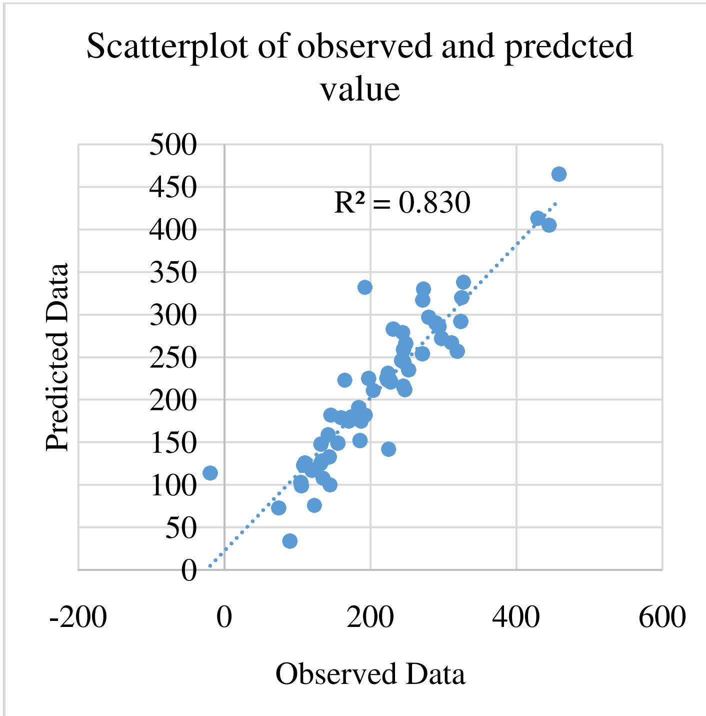
Source: Author, 2015

In general, higher the multiple and adjusted R-squared value the better would be the model fit and performance. The lower AICc value and Global Moran's I value represents better model result. According to Table 5, GWR model result is taken as the best fitted model for calculating walkability index. So the walkability index equation would be as follow:

$$\begin{aligned} Walkability\ Index \\ &= (NID \times 0.01349) + (LUM \times 776.5676) + (NRFA \times 0.001385) \\ &+ (NFFA \times 0.00012) - (NEIFA \times 0.02675) + (NRVA \times 0.00699) \\ &+ (NFA \times 0.033923) - 356.33262 \ldots\ldots\ldots\ldots (1) \end{aligned}$$

Model Calibration

To calibrate this model result, a prediction feature class was selected. The prediction feature class was the other 30% sample data. The model calculated predicted value of walking time per week for each 60 samples. The observed and predicted data were then plotted against each other. Figure 3 shows the scatter plot of predicted and observed value of 30% sample data.



Source: Author, 2015

Fig. 3: Scatter plot of observed and predicted value

From the figure it is seen that, the value of R2 has been found out optimal (0.8305). It indicates that the generated walkability index model equation's accuracy is 83.05%, which is quite good.

Calculation of Walkability Index for Each Wards of Khulna City

The built environmental criteria indices were prepared for each wards of Khulna City. Then the walkability index score for each wards were calculated using the equation (1) found from GWR model. Table 5 represent the values of each built environmental criteria and walkability score for each wards. Figure 4 shows the walkability score level for all wards of Khulna City.

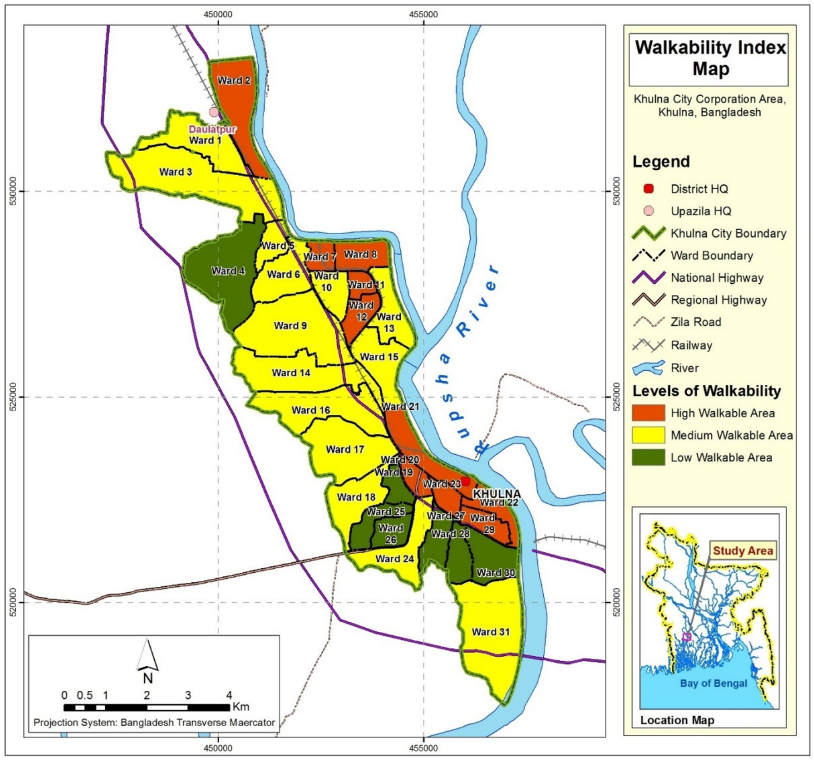
Table 5: Walkability index score summary for each wards

Ward No	NID	LUM	NRFA	NFFA	NEIFA	NRVA	NFA	Walkability Index Score	Levels of Walkability
1	0.00018	0.481	0.00036	0.942	0.0021	0.238	0.0063	17.92	Medium
2	0.00015	0.722	0.00020	0.982	0.0014	0.156	0.0090	204.99	High
3	0.00007	0.479	0.00015	0.705	0.0015	0.117	0.0048	15.78	Medium
4	0.00007	0.357	0.00019	0.653	0.0005	0.114	0.0025	-78.93	Low
5	0.00027	0.556	0.00048	0.979	0.0068	0.119	0.0149	76.01	Medium

Ward No	NID	LUM	NRFA	NFFA	NEIFA	NRVA	NFA	Walka bility Index Score	Levels of Walka bility
6	0.00020	0.577	0.00034	0.660	0.0091	0.145	0.0082	92.34	Medium
7	0.00022	0.591	0.00038	0.442	0.0008	0.095	0.0118	103.03	High
8	0.00023	0.701	0.00032	0.956	0.0037	0.164	0.0042	188.53	High
9	0.00013	0.520	0.00025	0.552	0.0011	0.085	0.0062	48.02	Medium
10	0.00031	0.587	0.00052	0.367	0.0088	0.129	0.0266	100.00	Medium
11	0.00042	0.680	0.00061	0.614	0.0033	0.113	0.0169	171.97	High
12	0.00026	0.593	0.00043	0.108	0.0081	0.160	0.0209	104.62	High
13	0.00007	0.590	0.00012	0.788	0.0010	0.066	0.0043	101.91	Medium
14	0.00013	0.498	0.00026	0.543	0.0046	0.129	0.0053	30.56	Medium
15	0.00018	0.562	0.00032	0.783	0.0023	0.113	0.0099	80.51	Medium
16	0.00023	0.540	0.00041	0.485	0.0045	0.174	0.0078	63.17	Medium
17	0.00016	0.551	0.00028	0.274	0.0036	0.109	0.0088	72.12	Medium
18	0.00016	0.540	0.00028	0.164	0.0028	0.113	0.0114	63.73	Medium
19	0.00036	0.443	0.00080	0.033	0.0086	0.094	0.0209	-11.92	Low
20	0.00029	0.669	0.00043	0.330	0.0046	0.031	0.0193	163.36	High
21	0.00025	0.704	0.00035	0.933	0.0022	0.040	0.0114	190.48	High
22	0.00033	0.694	0.00048	0.981	0.0173	0.104	0.0204	183.37	High
23	0.00024	0.678	0.00035	0.277	0.0202	0.071	0.0254	170.54	High
24	0.00031	0.494	0.00061	0.582	0.0038	0.143	0.0141	27.32	Medium
25	0.00031	0.412	0.00074	0.044	0.0060	0.187	0.0174	-35.71	Low
26	0.00033	0.447	0.00073	0.496	0.0039	0.137	0.0081	-8.85	Low
27	0.00030	0.435	0.00067	0.319	0.0031	0.131	0.0136	-17.88	Low
28	0.00026	0.327	0.00080	0.456	0.0034	0.228	0.0145	-102.1	Low
29	0.00032	0.599	0.00053	0.159	0.0059	0.139	0.0160	109.16	High
30	0.00031	0.426	0.00073	0.778	0.0039	0.131	0.0168	-24.94	Low
31	0.00012	0.558	0.00021	0.818	0.0010	0.162	0.0024	77.48	Medium

Source: Author, 2015

The highest level of walkability is found for Ward 21 and the Ward 28 represents the lowest level of walkability. Ward 21 contains Bara Bazar, Jora Gate, Railway Guar Colony, Railway Colony and Railway Market area. On the other hand, ward 28 contains major parts of Dakshin Tootpara, Karpara, Miah Para and Paschim Tootpara.



Source: Author, 2015

Fig. 4: Levels of walkability index score of Khulna City

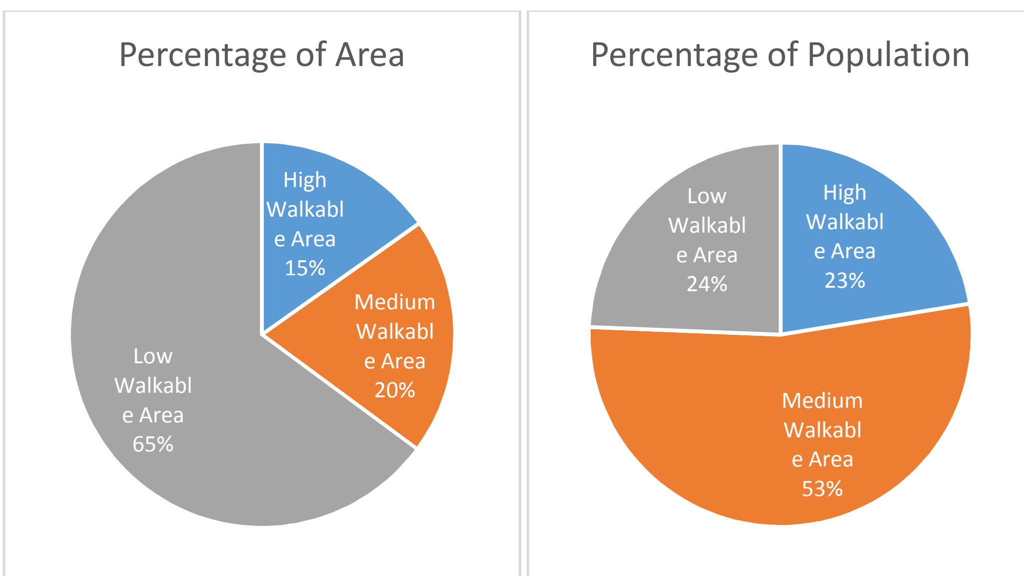


Fig. 5: Percentage of population and total area under each levels of walkability

From the pie charts it is seen that, maximum people (53%) lives in the medium walkable region of Khulna City. On the other hand, maximum area (65%) of Khulna City lies under the boundary of low walkable area. Only a few percentage of population lives in the high walkable areas.

Validating Walkability Index Model Rank

The validation of Walkability Index Model Rank (WIMR) was done through Residents' Perception Rank (RPR) for total 18 wards. Total 189 samples were selected to assess four variables i.e. reasons behind walking, safety on walking, obstacles for walking and satisfactory levels of footpaths in their corresponding wards.

Table 6: Calculation of residents' perception score and rank

Ward no	Reasons of Walking	Safety on Walking	Obstacles for Walking	Satisfactory Level of Footpaths	Score	Rank
5	1	1	-1.5	1	1.5	13
9	1	1	-1.5	2	2.5	11
10	1	3	-1.5	2	4.5	7
12	1	2	-2	1	2	12
14	2	3	-1.5	2	5.5	6
16	1	2	-1	1	3	9
17	2	3	-1	4	8	5
18	1	2	-2	2	3	8
19	1	1	-3.5	1	-0.5	17
20	2	3	-0.5	4	8.5	3
22	3	4	-0.5	4	10.5	1
23	2	4	-0.5	4	9.5	2
24	1	1	-2.5	1	0.5	15
25	1	1	-3	1	0	16
27	1	2	-1.5	1	2.5	10
28	1	1	-4	1	-1	18
29	2	4	-1	3	8	4
30	1	1	-2	1	1	14

Source: Author, 2015

The spearman's rank correlation was found 0.818369, which means there is a good correlation among the two ranking systems. So it can be concluded that the index scores calculated for each ward using walkability index model is correlated with the scores found from residents' perception.

Conclusion

Walkability assessment of a city or neighborhood needs proper analysis of factors and socio economic condition of that region. This study intended to find out the built environmental attributes affecting walking behavior and a model which can determine the level of walkability for different neighborhoods of Khulna City. This study shows the influence of the built environmental criteria on walking. According to the analysis, the most influencing criteria has been found as land use mix. The most walkable area is found for Ward no 22 where the least walkable area is found for Ward no 4.

Outcomes of the study could be an appropriate guide for urban planners, city managers and decision makers to acknowledge a proper vision related to walkability. They can also incorporate the outcomes while preparing the development plan and can solve urban health problems. This study can also encourage measuring walkability for other big cities in Bangladesh. The Walkability index can be useful is in the stage of urban planning. High value of Walkability index means that a particular arrangement of the city supports physical activity of people. The low value of Walkability index means that people very often used cars in the everyday life which results into minimum physical activity. The enumeration of the Walkability index is possible for both existing structure of the town and for any proposed urban plan. It is, therefore, a good opportunity for urban planners to evaluate the proposed urban plan from the point of influence on the peoples´ physical activities. Urban planner can so increase the everyday physical activities of citizen by good arrangement of streets and high diversity of land use.

Though there were some limitations during the study procedure, the results show the level of walkability of all wards of Khulna City and peoples' perception on walking in their neighborhoods. In developed countries various studies have been done to identify level of walkability for different places, but for developing countries like Bangladesh, it is unprecedented. This is the first approach to develop a model by which walkability can be measured for Khulna City. Further researches incorporating more precise data and variables could lead to more sophisticate and accurate walkability index model.

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