Potential Hospital Location Selection Using Fuzzy-AHP: An Empirical Study in Rural India

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Abstract - **Selection of a location for a potential hospital is a strategic issue and often decides the fate of such a facility. It is thus important to evaluate the locations from multiple dimensions including subjective and objective factors before selecting a site as the decision cannot be reverted in case it goes wrong. This paper makes an attempt to perform a multi criteria evaluation of potential hospital locations using Fuzzy Analytical Hierarchy process (FAHP) using a case of three potential rural sites in India. Three major factors and eleven sub factors are considered for the location selection evaluation. Findings show that among the sub factors, cost of land, population density and proximity to public transport evolved as the three most significant sub factors.**

Key words: **Hospital location, FAHP, multi criteria decision making, pair wise comparison, selection, expert opinion**

I. INTRODUCTION

After the British left India in 1947 leaving behind miserable poverty in the country, independent India continued with most of its citizens having very low-income with life expectancy just about 27 years. Since then there has been metamorphic change in the economic growth of the nation and the progress is well witnessed by the world. The financial conditions of the country improved to such an extent that the country is in a position to give loans to small countries.

However the difference between the rich and the poor has widened over the years, leaving behind large parts of the country under poverty. The drastic improvements in sanitation and food position have improved the average life expectancy of the people of the nation to some extent but even today 70 per cent of the children in the rural areas are suffering from malnutrition and diseases because of lack of hemoglobin [6].

Added to that is the problem of economic and social inequality that is detrimental to the health of the populations. It is more so when the average healthcare expenditure borne by the government is 17% and the out of pocket expenditure of a common man is around 83%. Almost 33% of the people hospitalized are paying out of pocket for their healthcare need borrowing money at higher interest rates which intern pushes them below the poverty line. This problem multiplies when it comes to rural India. Studies reveal that the per capita expenditure on public health in the country is seven times lower in rural areas, compared to government spending for urban areas [2].

The growing population of a country always led to the demand of new healthcare facilities and India is not an exception. It is true that with a growing economy lot of private health care facilities are coming up but mostly catering to the upper and upper middle class of the society. For the lower and lower middle class the facilities are very limited especially in the rural areas may be because of the fact that the access to healthcare to this section of society is critically linked with public financing of healthcare services [3]. Health outcomes like infant mortality rate, life expectancy, under-5year mortality rate are also closely associated with the ratio of public investment in the health sector. It is not only the developed countries like Canada, Australia, Sweden, United Kingdom etc. but also countries like Sri Lanka, China, Costa Rica, Thailand, South Korea and Turkey who have put in efforts in their healthcare delivery and thus outperformed India in a greater extent [3].

Moreover from the WHO report it can be seen that the number of beds per 10000 population in India is only 9 (in-patient and maternity), much less than even Bhutan, Thailand, Malaysia, and Nepal whereas the global standard is 30. One may argue that these countries are smaller in size but even bigger countries like china is well ahead with 42 beds per 10000 citizens [22].

Interestingly the pattern of development of the health sector is closely linked to the political economy and the level of economic development. While economic development can create conditions for better access to healthcare, depending largely on private health financing can create large adversities for health not only for the poorer sections of society but also for the middle classes. Thus it is important to establish public healthcare facilities including hospitals to improve healthcare reach in the country irrespective of financial, social, geographical and rural-urban differentiation [16].

The above situation amplifies the need for new public hospitals to be set up by the Government for the poorer sections of the society who cannot spend a huge amount in healthcare. The available healthcare infrastructure is not adequate to cater to all sections of the society. The irony here is that even the available healthcare does not reach the needy in a country that produces the largest number of doctors and nurses in the world every year [1].

II. REVIEW OF RELATED LITERATURE

Creating healthcare facility and its success always brings in the concerns for quality. It is true that the absence of quality medical personnel is a genuine concern, but this only cannot guarantee the quality of the service provided to the society [19]. Physical access matters significantly and thus the selection of the location for the facility becomes a strategic issue as it is related to the medical service quality [13]. The success of such a facility depends on how it attracts the potential patients [8] and selection of the location must address issues related to environmental factors, economic, distance and social conveniences or inconveniences [20]. Because of the structure and the multi-criteria nature of the hospital site selection decisions, this sort of decision making attracts personal and subjective analysis than objective analysis [5].

Studies are available on health care facility location and the travel time methodology is one of the prominent techniques used by the researchers across the globe ([10]; [4]; [7]; [12]). This analysis requires extensive amount of data related to cost grid or travel time and in most of these research works that data was provided by the concerned department of transportation. In Indian context this is a real problem. Moreover this modeling uses Zip codes which often contain geographic data error that leads to wrong population totals when modeled using area based methodology [21].

When we talk about multi criteria decision making the tool which is extensively used by different researchers across different fields of study is the Analytical Hierarchy Process by Saaty[17]. Although there are a very few studies available in hospital site selection using Analytical Hierarchy Process (AHP) or its fuzzy extended form (FAHP), but all of them are done in countries other than India and that too in an urban metropolitan area. Based on the review of existing literature it can be inferred that no study has been done on site selection of public funded hospital in rural India where Fuzzy AHP is used as a location selection tool.

This study attempts to assess three potential hospital sites in rural India using FAHP approach. The objective is to see how well FAHP can capture the qualitative differences existing among the alternative locations across different dimensions with the help of fuzzy linguistic preference scale and help the planners in selecting an appropriate hospital location.

III. METHODOLOGY

The application of fuzzy analytical hierarchy process uses different steps including respondent selection, alternative identification, identification of factors and sub factors for evaluation and generations of factor weights and alternative scores. The final alternative scores help us in identifying the best alternative.

A. *Respondent selection*

Since fuzzy analytical hierarchy process (FAHP) is mainly based on a subjective decision making, it requires reliable inputs for efficacy and consistency of the results. Inconsistent inputs can lead to wrong interpretations and thus the character of FAHP asks 'expert opinion' for consistent factor weight evaluations. In this hospital site selection problem the twelve selected experts are medical doctors having more than fifteen years of experience in the field of hospital or health care administration and health care projects and are quite acquainted with all the three alternative locations in the Durgapur sub-division of West Bengal, India selected for the present study. Most of them worked in Durgapur sub division for more than 10 years at different levels including HOD and medical superintendent. These experts are selected based on the convenience of the researcher keeping the above mentioned qualification in mind. The comparisons are done to identify the level of importance of one over the other using a linguistic scale. Though the scales in which expert judgments are captured are the same but associated to crisp and fuzzy numbers depending on the model used. Here one thing to be noted is that the comparisons are done only within similar level i.e. no sub factor is ever compared with a factor or with an alternative.

Once the responses are captured using the questionnaires from 12 select experts, which is believed to be an adequate size by Okoli, an attempt has been made to generate consensus among the expert's opinion. In case of significant response variation the average value is considered whereas in case of extreme divergence the outlier is ignored.

B.   Selection of factors and sub factors for the study

The identification of factors and sub factors for the evaluation of locations for potential hospitals is one of the most important tasks under the multi criteria decision making (MCDM) approach. This evaluation of potential location is carried out using different sub factors from multiple dimensions.

A number of researchers who voiced for multi criteria evaluation of a hospital site recommended a wide range of site selection criteria. Vahinia considered distance from arterial routes, travel time, contamination, land cost and population density as the set of factors for evaluation, whereas Soltani talked about distance to major roads, distance to other medical centers, population density and parcel size of the land ([19]; [20]). In the optimal site selection for Taiwanese hospitals, Wu considered, population size, age, density, governmental policies, capital, labour and land where Schuurman discussed the importance of socio demographics of the service area, proximity to future expansion, space, travel time and population density([23]; [18]). Based on the prominence in the available literature and opinions of the experts consulted, the criteria for evaluation are broadly classified as 'cost', 'population characteristics' and 'location' with eleven sub factors under the three major factors considered in the present study. The factors and sub factors are summarized in **Table 1**. Moreover the same set of factors and sub factors are considered in the studies using AHP and FAHP models respectively in the following chapters.

Table 1

Major factors and sub factors

| Major Factor	Sub Factors
Cost ([19]; [15]; [20]; [23])	Cost of land
	Land Topography
	Land ownership
	Running/ Maintenance cost
Population characteristics ([19]; [18]; [20]; [23],)	Population density
	Education
	Economic condition
Location ([20]; [19]; [15])	Proximity to Public transport
	Space for future construction
	Availability of existing infrastructure
	Proximity to market

C. *Identification of the alternatives for the study*

Identification of the alternative locations for the study is equally important in both AHP and FAHP methods. These identified alternatives are the set of potential sites from which we select the best using the MCDM techniques like AHP or FAHP. This is a common phase in both AHP and FAHP methods.

The study area for this hospital site selection problem is in Durgapur sub division under district of Burdwan, West Bengal, India. The selection of the study area is based on the convenience of the researcher keeping in view the demographic profile of its surrounding places. **Figure 1** shows the map of the district of Burdwan which explains the position of the three potential rural locations namely Faridpur, Kanksa and Pandabeswar selected for the purpose of the study [11].

Figure 1

Map of the district of Burdwan
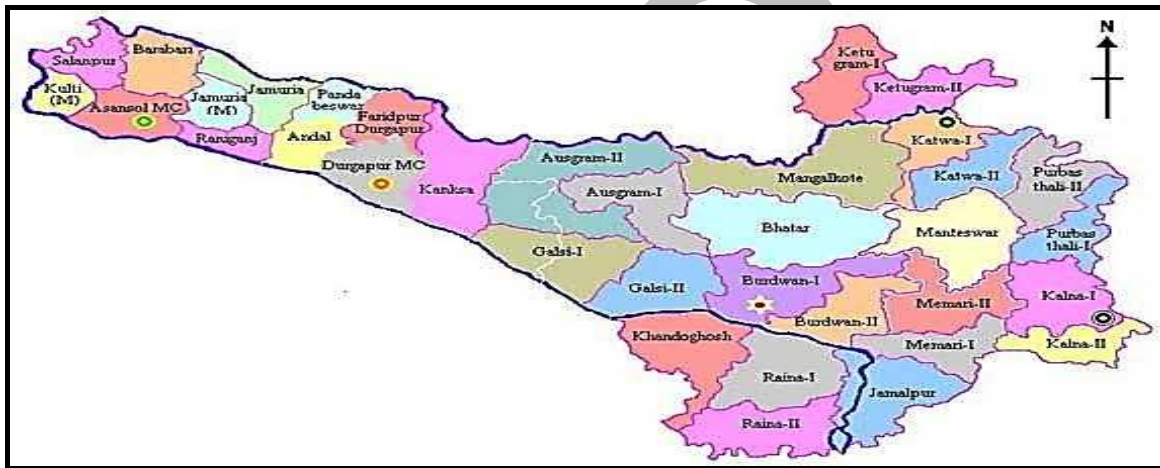
Source: NREGS, Burdwan district (http://nregsburdwan.com)

From the medical facility and population of the district of Burdwan([9];[14]), West Bengal (http://www.bardhaman.gov.in/health/medifaci.html and http://www.bardhaman.gov.in/census/popliterate.html) one can see that in spite of a population of more than a lakh in each of these three locations, no hospital exists that can cater to the country people of the regions. Though there are a handful number of nursing homes and clinics available but are beyond the reach of the poorer section of the society. The condition in terms of bed per 1000 population is even worse than that of the nation's average. **Table 2** depicts the detail of the three alternate locations and the serious healthcare facility problem therein.

One major reason for selecting these locations among the other available blocks under the sub division of Durgapur, West Bengal could be because of the homogeneity in terms of the population, percentage of SC & ST in the community, education, source of income, atmospheric conditions and the disease profiles.

Table 2 Population and hospital detail of the study area

Area	Population	Hospitals	Health center	Doctors
Pandabeswar (HS3)	146445	0	4	4
Faridpur (HS1)	108619	0	2	3
Kanksa (HS2)	151255	0	5	7

Source: adopted from Medical facility & population, bardhaman.gov.in

Looking at the positive characteristics for building a health facility in these alternative locations one can see that all these three locations are well connected through rail and roads and are having sufficient water from the rivers like Damodar and Ajay. Moreover all these places are connected to electricity supply,

drainage and some amount of greenery around for a better healing environment.

D.   *Construction of the detail hierarchy of the problem*

The hierarchy in AHP as well as FAHP starts with the objective or goal of the decision problem. This is also a common phase of both non-fuzzy and fuzzy analytical hierarchy processes. Here the goal is to evaluate all the alternative sites for a potential hospital with respect to the factors and sub factors considered in the study.

The factors and sub factors responsible for evaluation of alternative hospital sites are placed in subsequent levels next to the objective. The factors are placed next to the objective whereas the sub factors are placed in the next level under the respective parent factors. For example the three sub factors 'population

density', 'education' and 'economic condition' under the factor 'population characteristics' are placed below the parent factor and are compared among them. The bottom level contains the alternative sites to be evaluated.

When it comes to pair wise comparison, the factors are compared within themselves whereas the sub factors under each factor are only compared i.e. a sub factor of a factor is never compared with another sub factor under a different factor. In the cases of the alternatives, they are compared among themselves with respect to each of the sub factors available in the study. Alternatives are never compared with respect to the factors considered in the site selection exercise. Finally the weights of the alternatives generated with respect to each of the sub factors are aggregated. **Figure 2** describes the hierarchy of the site selection problem.

Figure 2

Hierarchy of the hospital site selection problem
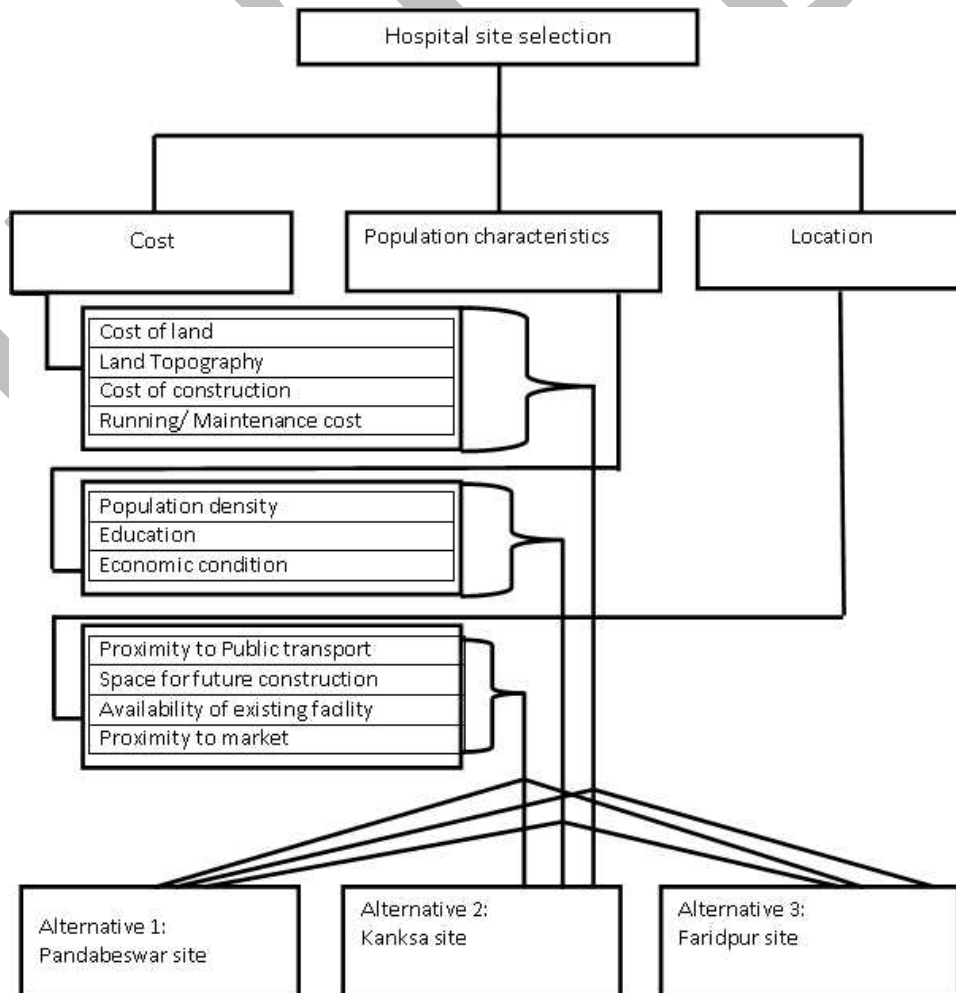
E. *Generation of factor weight*

Although the pair wise comparisons in FAHP are done using the same linguistic terms as used in AHP, but is processed using the numerical values obtained from the fuzzy linguistic scale proposed by Pan (2008) after modifying Chen's scale (Chen, 2000). Five linguistic terms 'extremely unimportant', 'moderately un important', 'equally important', 'moderately important' and 'extremely important' ranging between 0 to 10 are used to develop fuzzy comparison matrices. One difference to be noted here is that though the same set of linguistic terms are used by Saaty but they were crisp numbers without the concept of pessimistic, most likely and optimistic response values. In FAHP these linguistic terms are represented by triangular fuzzy numbers (TFN) each with a lower, middle and an upper value.

The first step is to compile the expert responses into the pair wise comparison matrices as illustrated by equation 8.1.

Let us understand the initial pair wise comparison matrix corresponding to the factor 'cost'. Let the matrix is represented by $\tilde{A}$ where

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (8,9,10) & (8,9,10) & (8,9,10) \\ (0,1,2) & (1,1,1) & (3,5,7) & (3,5,7) \\ (0,1,2) & (3,5,7) & (1,1,1) & (6,7.5,9) \\ (0,1,2) & (3,5,7) & (1,2.5,4) & (1,1,1) \end{bmatrix} \dots (8.1)$$

Now to simplify the calculation of factor weight corresponding to 'cost', the fuzzy pair wise comparison matrix in (8.1) is split into crisp matrices formed by taking the minimum values ($\tilde{A}_L$), most plausible values ($\tilde{A}_M$), & maximum values ($\tilde{A}_U$), from the triangular fuzzy numbers (Pan, 2008). Thus the matrix with the sub factors under 'cost' involving maximum values, most plausible values and minimum values are given respectively by

$$\tilde{A}_U = \begin{bmatrix} 1 & 10 & 10 & 10 \\ 2 & 1 & 7 & 7 \\ 2 & 7 & 1 & 9 \\ 2 & 7 & 4 & 1 \end{bmatrix} \dots (8.2)$$

$$\tilde{A}_M = \begin{bmatrix} 1 & 9 & 9 & 9 \\ 1 & 1 & 5 & 5 \\ 1 & 5 & 1 & 7.5 \\ 1 & 5 & 2.5 & 1 \end{bmatrix} \dots (8.3)$$

and

$$\tilde{A}_L = \begin{bmatrix} 1 & 8 & 8 & 8 \\ 0 & 1 & 3 & 3 \\ 0 & 3 & 1 & 6 \\ 0 & 3 & 1 & 1 \end{bmatrix} \dots (8.4)$$

Now let us denote the sub factors 'cost of land', 'land topography', 'land ownership' and 'running/maintenance cost' by C1, C2, C3 and C4 respectively and generate the weights for the sub factors.

From the maximum value matrix in equation (8.2), the geometric mean of cost of land (C1) with respect to the other sub factors C2, C3 and C4 can be calculated. Thus the geometric mean of C1 is

$$v_1 = (1 \times 10 \times 10 \times 10)^{\frac{1}{4}} = 5.623 \dots (8.5)$$

Following the similar calculations the geometric mean of C2, C3 and C4 are obtained as 3.146, 3.35 and 2.735 respectively. Hence the relative weight of C1 can be calculated as

$$w_1 = \frac{5.623}{5.623 + 3.146 + 3.35 + 2.735} = 0.3785 \dots (8.6)$$

. Following the similar calculations as described in equation (8.6) the maximum weights of C2, C3 and C4 are calculated as 0.212, 0.225 and 0.184 respectively.

From the 'most likely' matrix $\tilde{A}_M$ the geometric mean of C1 can be calculated by $v_1 = (1 \times 9 \times 9 \times 9)^{\frac{1}{4}} = 5.196$. Similarly the geometric mean of C2, C3 and C4 in the matrix $\tilde{A}_M$ are calculated as 2.236, 2.474 and 1.88. Hence following the calculation in equation (8.6) 'most likely' weights of C1, C2, C3 and C4 are 0.4408, 0.1897, 0.2099 and 0.1595.

From the matrix $\tilde{A}_L$ the geometric mean of C1 can be calculated by $(1 \times 8 \times 8 \times 8)^{\frac{1}{4}} = 4.768$. Interestingly the geometric means of C2, C3 and C4 are obtained as 0. Hence the relative weights of C1, C2, C3 and C4 corresponding to the 'pessimistic' matrix are respectively 1, 0, 0 and 0. Thus the fuzzy weights of the sub factors C1, C2, C3 and C4 under 'pessimistic', 'most likely' and 'optimistic' decision making environment can be seen from Table 3.

Table 3 : Fuzzy weights of the sub factors under 'cost'

Decision situations ->	Pessimistic	Most likely	Optimistic
Sub factors	(l	m	u)
C1	1	0.440832	0.378536
C2	0	0.189704	0.211794
C3	0	0.209942	0.225528
C4	0	0.159521	0.184143

After the computation of fuzzy factor and sub factor weights corresponding to the optimistic, most likely and pessimistic decision making environments, it is important to defuzzify the existing fuzzy weights corresponding to the factors and sub factors to obtain the crisp weight. The reason behind this is to see the percentage contribution of the weights of the sub factors within the main factor in the evaluation.

From the example of 'cost', the fuzzy weights of the sub factors within it can be defuzzified and the crisp weights of the sub factor C1 under 'cost' can be calculated by $\frac{(1+2\times0.4408+0.3785)}{4}$ =0.5651. Similarly the crisp weights of C2, C3 and C4 are 0.1478, 0.1614 and 0.1258 respectively.

IV. RESULTS AND DISCUSSION

Once the responses are converted into fuzzy factor weights using the steps mentioned in the previous section, it is important to see what the result shows. From Table 4 we can see that all the pessimistic,

Table 4: Fuzzy weights of the main factors

Factors	Weight of main factors		
	(l	m	u)
Cost	0.53353128	0.4521	0.4160
Population Characteristics	0.23323436	0.2740	0.2920
Location	0.23323436	0.2740	0.2920

From the hierarchical structure of the location selection decision problem explained in Figure 2, it can be understood that the global weights of the sub factors in this study inherit the weights of the parent factor therein, i.e. the sub factors under 'cost' inherit the weight of the parent factor and the fuzzy global weights of the sub factors namely 'cost of land', 'land topography', 'land ownership' and 'running/maintenance cost' are computed through the multiplication of their respective fuzzy weights and the parent weight.

### F. Calculation of score for alternatives

Alternative fuzzy scores are also generated in the same way as the weight generation is done for factors and sub factors. The global fuzzy scores of the alternatives are calculated by multiplying the relative fuzzy weights of the alternatives with the corresponding sub factor weights. For example the fuzzy scores of the alternatives with respect to 'cost of land' is multiplied by the global weight of the sub factor 'cost of land' to generate the global scores of the alternatives. The process takes care of the inclusion of the relative weights of the sub factor and also its parent factor in the evaluation of scores for the alternatives.

The overall fuzzy weights of the alternatives are calculated by aggregating the global scores of the alternatives with respect to the individual sub factors. These overall fuzzy weights of the alternatives are finally defuzzified to provide crisp scores for better understanding of the ranks of alternative locations for hospitals.

most likely or the optimistic values for the factor 'cost' is much higher than that of its other counterparts. Though the table represents the fuzzy weights of the factors but it is difficult to see the percentage contribution of the factors in the evaluation exercise.

The defuzzified scores can only tell the true story. Figure 3 represents the defuzzified weights of the factors which tell us that 'cost' itself has got its importance at the level of 46%, followed by both 'population characteristics' and 'location' at 27% each.

Figure 3: Contribution of the factors in the evaluation
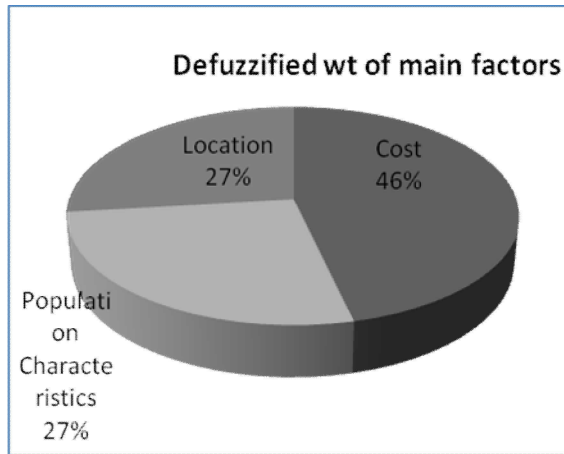
Looking at the sub factors and their importance within the main parent factor one can understand how the weights are distributed among the sub factors in the present study. From Figure 4 one can see that the weight of the sub factor 'cost of land' alone is 0.5651 i.e. 56.5% followed by its counterparts with a maximum weight at the level of 16%. Moreover it can be understood that the contribution of the sub factors 'land topography', 'land ownership' and 'running maintenance cost' are almost equal.

**Figure 4: Fuzzy weights of the sub factors under cost**
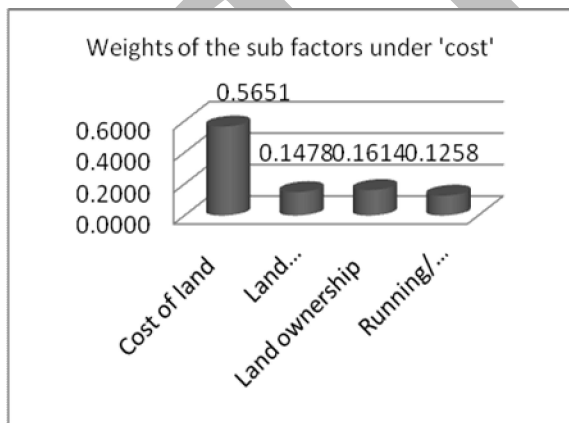
Figure 5 demonstrates the distribution of weights of the sub factors within the factor 'population characteristics'. From the figure one can understand that 'population density' leads with a weight of 0.5429 i.e. an importance of 54.29% followed by 'economic conditions' at a level of 29% and 'education' at 16.63%.

Figure 5: Fuzzy weights of the sub factors underpopulation characteristics
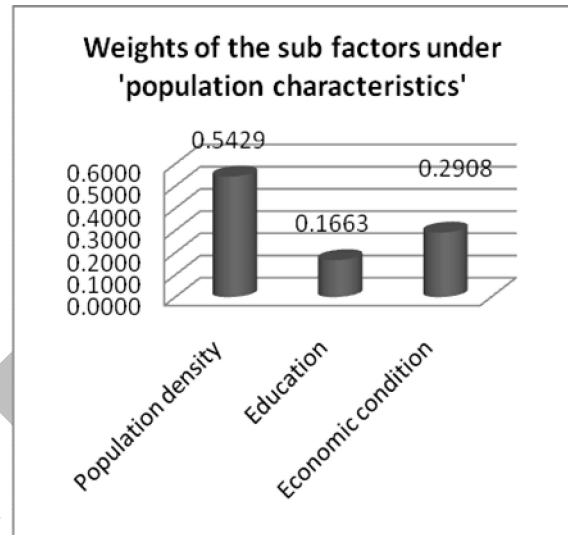
In the factor 'location' the importance of the sub factor 'proximity to public transport' is the highest with 41% followed by 'proximity to market' at 33%. The other two sub factors 'space for future construction' and 'availability of existing infrastructure' are at the level of 15% and 10% respectively. One thing can be noted in the present study that proximity played a vital role within the factor 'location', be it public transport or market.

Figure 6: Fuzzy weights of the sub factors under location
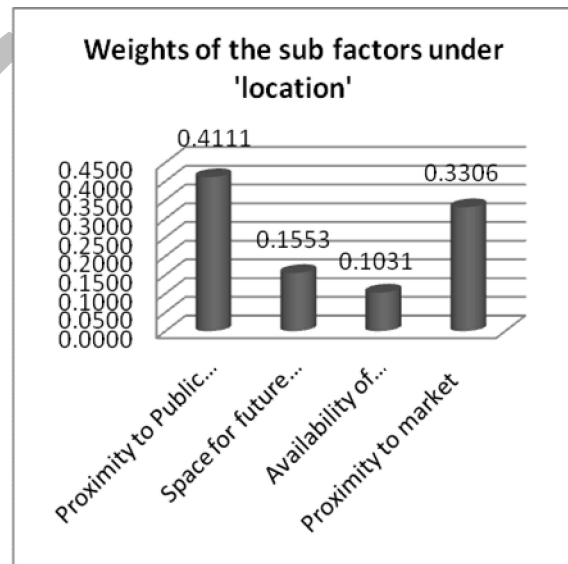
Since the entire study is done in the context of rural India, proximity of that location plays an important role in the success of the future health facility because the population it is supposed to cater can't

afford higher charges of transportation neither possesses their own means of transportation. In most of the cases they rely on the existing public transportation and hence proximity is what evolves as one of the major constraint.

Looking at the results of the study in terms of global weights of all the sub factors, one can see from Figure 7 that 'cost of land', 'population density', 'proximity to public transport', 'proximity to market' and 'economic conditions' play important roles in the evaluation of potential location for hospitals in rural India.

Once the weights of the factors and sub factors are determined it is important to see the alternative scores with respect to the sub factors considered in the study.

Looking at the global scores of the alternative locations from Figure 8 one can see significant variations of alternative scores with respect to the sub factors. It is true that in most of the sub factors the scores of Faridpur and Kanksa are very near to each other but significant variations are observed in case of the third alternative location. Though in most of the sub factors the scores of Pandabeswar is less but w.r.t population density and economic condition it outperforms the other two competitors.

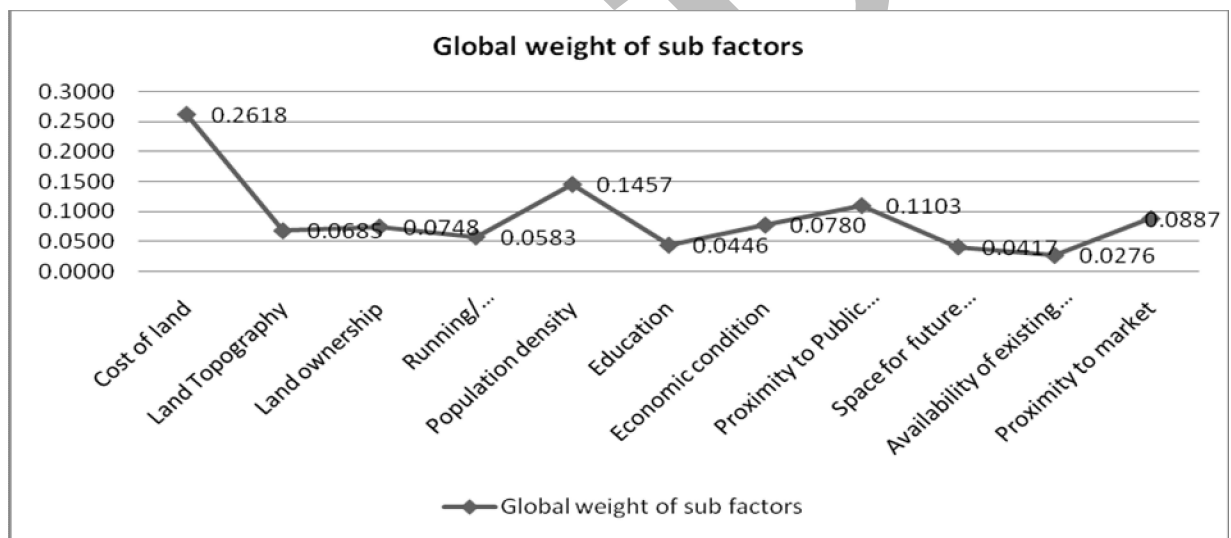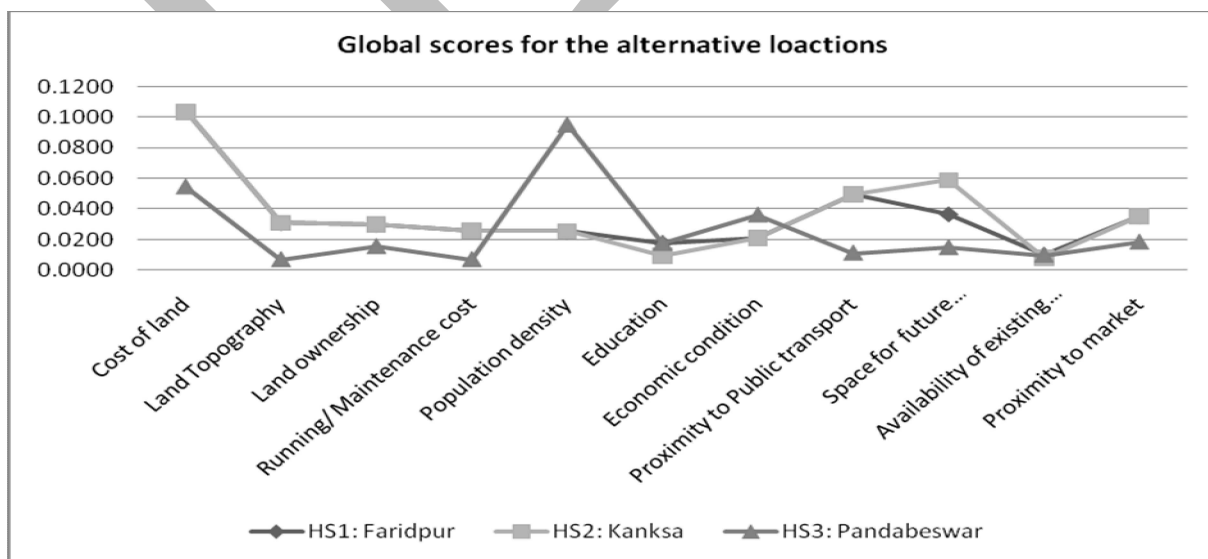**Figure 7: Global fuzzy weights of the sub factors**

Figure 8: Global scores of the alternatives locations

Combining the scores obtained by the three alternative locations: Faridpur, Kanksa and Pandabeswar with respect to all the sub factors it can be observed from Figure 9 that Kanksa evolves as the best potential site for a hospital in the context of rural India.

Though Faridpur stands second among the three alternatives taken in the study, but minute observations yields that the difference is not significant with respect to most of the sub factors considered individually.

Figure 9: Final scores of the alternatives locations

Final scores for the alternatives
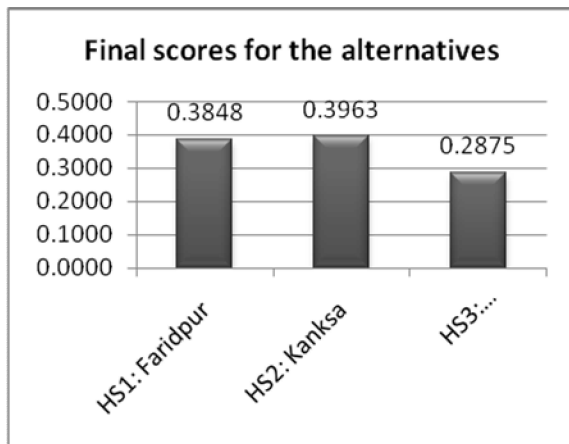
V. CONCLUSION

The present study never witnessed any study on multi criteria evaluation of potential hospital sites in rural India in the existing literature. Moreover, going through such a study one can easily understand that most of the factors and sub factors considered in the study are intangible or subjective in nature and it is thus very important to capture them properly for precise results.

The fuzzy analytical hierarchy process helps capture the subjective judgments by the use of fuzzy linguistic preference scale and the results obtained in the study are in line with many previous studies conducted, apart from the fact that 'cost' evolves as the most important factor in the present study. Since most of the previous studies are done in urban area or metropolitan area of a country differing significantly from India in terms of population size, economy, geography and culture, the variation in result is quite understandable.

Though the use of FAHP makes the site selection more meaningful, but the limitation is the efficiency of the method in dealing with large number of factors or alternatives. Because of the huge computation it is

advisable to use the method on select alternatives. However the use of software can solve this problem to a great extent.

The present study can be extended to location analysis of specialty hospitals with a different set of factors and sub factors necessary for the evaluation of such category of hospitals. The study can further be extended to a comparative analysis between the select factors and sub factors for location analysis of healthcare facilities funded by private or public entity.

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