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Suitability Assessment for Selecting New Sites for Installing Water Service Centres within English Bazar Municipality, Malda, West Bengal

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ABSTRACT

Being the sole emerging district town of Malda, English Bazar Municipality (area: 13.25 km^2) is highly populated (total population=216,083), severely suffering from insufficient safe drinking water. It has attempted to supply purified safe drinking water through some water service centres (locally called Jaladhar) from where most of the people collect the necessary drinking water. There are 72 such service centres, spatially distributed in 29 wards of this municipality. Due to unequal population distribution and varying growth of population, it is essential to review whether the existing distribution is rational. Therefore, we attempted to find out some suitable sites, where additional water service centres are required, based on six demand parameters (population density, public service centre, existing water supply centres, location of bus stand, centroid of the ward/mouzas, land use as accessible point). From this purpose, both knowledge based and objective weighted composite index based spatial models have been prepared. Slightly different results have been yielded by the two models but the trends of site selection proved to be almost identical. About 4.29% out of total area, covering wards number 9, 15 and 19, have proved to be in high demand of high water service centres, mainly located in the core area of the municipality.

1. INTRODUCTION

In the 20th century, the threefold increase of population has triggered six fold hiking of water use [1]. By 2050, the world population is projected to reach about 10 billion and seventy per cent of them will live in urban areas [2]. Growing urbanization and industrialization emit pollution to the environment. Widespread pollution has enforced quality freshwater scarce, posing threats to human health and biodiversity [3]. Simultaneously, nutrient abundance in fresh natural waters has become one of the major vectors tainting ground water particularly since the agricultural revolution of the 1960s and 1970s [4], [5] and [6]. In urban areas, particularly, untreated or semi treated human waste also causes significant water quality degradation [4]. Due to such access to unsafe water, every year approximately 1.3 million deaths are registered globally [7]. Amid this entrapped circumstances, the recommendation of UNO of at least 20 L of safe drinking water/ person/ day [1] is one of the emerging challenges in relation with sustainable development, wellbeing and human health [2]. According to UNO, safe drinking water can be defined in terms of criteria, e.g. (1) the quantity of water, (2) the safeness or quality of water, and (3) the distance for collecting water [1]. Rapid environmental transformations, including climate change, have compelled us to face the question how the planet will adopt the extra three billion people by 2050. Also, at present, more than one billion people suffer from unsafe drinking water [8]. Although in last two decades tremendous advancement for providing safe water was made, there are still 800 million people without access to quality water [9].

Quantity crisis always emerges not only due to the scarcity of water but also due to wastage of water and irrational distribution. Present global extraction of water is of 4000 km^3 annually, out of which 2600 km^3 is consumed and the rest of 1400 km^3 accounts for conveyance and appliance loss [10]. Therefore, rational application and conveyance could save huge amounts of water and could support 1/3rd of extra world's population every year. Apart from the human end, nature sometimes bears deep responsibility for degrading water quality. The water in the area considered in the present study comes from underground, under arsenic borne layers, which cause arsenic contamination. This poses extra burden for supplying safe water to the domestic households of the study area as well as in the metropolitan towns in India such as Mumbai, Delhi etc.

This problem is also a vitally socio-political issue and it may also be the same for the medium scale town, namely the English Bazar Municipality. Here, the scarcity of water is less important than water quality. High arsenic and iron content water in this area is withstanding against safe accessibility of water. In West Bengal, 44% of the total 88 million population is suffering from arsenic diseases [11]. Previously, in West Bengal, only shallow aquifers were infected with arsenic, but at present deep aquifers are also affected by the same problem [12], [13]. In West Bengal, arsenic content varies from 0.05-3.7mg./l with an average content of 0.2mg/l [11].

Malda, Murshidabad and Nadia districts of West Bengal where in most of parts, the arsenic contamination is beyond permissible limit (0.05 mg./l as per WHO) and people are severely affected by this problem in terms of arsenicosis and damage of food chain [14]. Considering all these real issues, the local government has taken initiative for distributing safe water to the people through some mega arsenic remover system. The District profile depicts that 15.08 lakh population (44 per cent of the rural population) are provided with water through 45 existing pipe water supply schemes (PWSSs), while 15,889 spot sources (tube wells) are functional in the District to provide potable water to the people. The District has seven arsenic affected blocks, namely the English Bazar, Kaliachak -I, Kaliachak -II, Kaliachak -III, Manikchak, Ratua-I and Ratua -II. Some measures have been taken by the Government to provide purified drinking water to the people of rural and urban area in the form of some scheme such as: Accelerated Rural Water Supply Programme (ARWSP), with component schemes, Water Quality Sub-Mission (WQSM) and Swajaldhara schemes as component schemes. In case of English Bazar Municipality the similar drinking water problem is found. The upper class people of the urban area depend on arsenic free drinking water like Drops, Bislery etc. But middle and lower class people depend on water supplied from municipal authority. To provide them with safe water ward, a specific pure water service centre has been installed, locally known as Jaladhar. Yet, disparities exist in their distribution in reference to population density and obviously over time as the population density as well as demand pattern is changing, which makes it necessary to timely review the distribution of water through the service centre.

Keeping this urgency in mind, the present paper concentrates onto finding out a new proposed location for water service centre considering the population density and some other relevant factors. Secondly, it is often rightly thought that while working with multi criteria decision making, there is need for weighted composition and weight should certainly be provided to the parameters objectively. But sometimes, judicious assignment of weight to the employed parameters toward aim can also yield a good result. In this paper, considering some sets of parameters, both subjective and objective weighted composite models have been prepared and compared for establishing the above statement.

2. STUDY AREA

The present study area consists of 29 wards of English Bazar Municipality (EBM), 16 surrounding mouzas from English Bazar block and 11 mouzas from Old Malda block covering an area of about 5,465.43 ha. (100ha. =1sq.km.). The entire study area comes under Diara tract of West Bengal with fertile fine grain silty clay carried out by river Ganga and its tributaries, Kalindri River and Mahananda River. Kalindri River and Mahananda rivers are located at northern and eastern margin of the study area. In the western part is located the Chatra wetland, typically characterizing the study area. Such location of natural components should have strong effects on the expansion and intensity pattern on the urban area. The average elevation of this region is 17 m from MSL.

The north-western part of the present study area is covered with mango orchards, which was almost 50% of the present study area 50 years ago. Chatra wetland (perennial) considered as the lungs of the town is located just nearby this town. Over time this wetland area has been captured by built up area. The climate of this region is characterized by sub tropical monsoon with seasonal wet and dry spell of rainfall, cold and hot spell of temperature. The entire year is sub divided by majorly four seasons: (1) winter season (January and February), (2) Premonsoon season (March to May) with little rain and high temperature and evaporation, (3) Monsoon season (June to Mid October) with maximum rain (about 82% of total rain) and high temperatures and (4) Post monsoon season (Mid October to Mid December) with steady declining of rain and temperature. The average annual rainfall of this area as gauged by Malda meteorological station is of 1,444.432 mm. The average potential evaporation of this area since 1901 to 2014 is of 73.45 mm./year, which indicates one of the controlling factors of surface temperature. This region is highly prone to the arsenic issue. The depth of ground water level is 8.53 m below the ground water level and over time it declines with very steady rate (linear regression model $y= 0.3303x+655.73$ and co-efficient of determination = 0.7303). The fluctuation of seasonal ground water level is of about 3 m and this phenomenon is highly determined by the seasonal rainfall pattern. The growth rate of population is very high (21.5% since 2001 to 2011). The spatial growth of the town is not proportional with population growth thereon, thus, population pressure rising steadily.

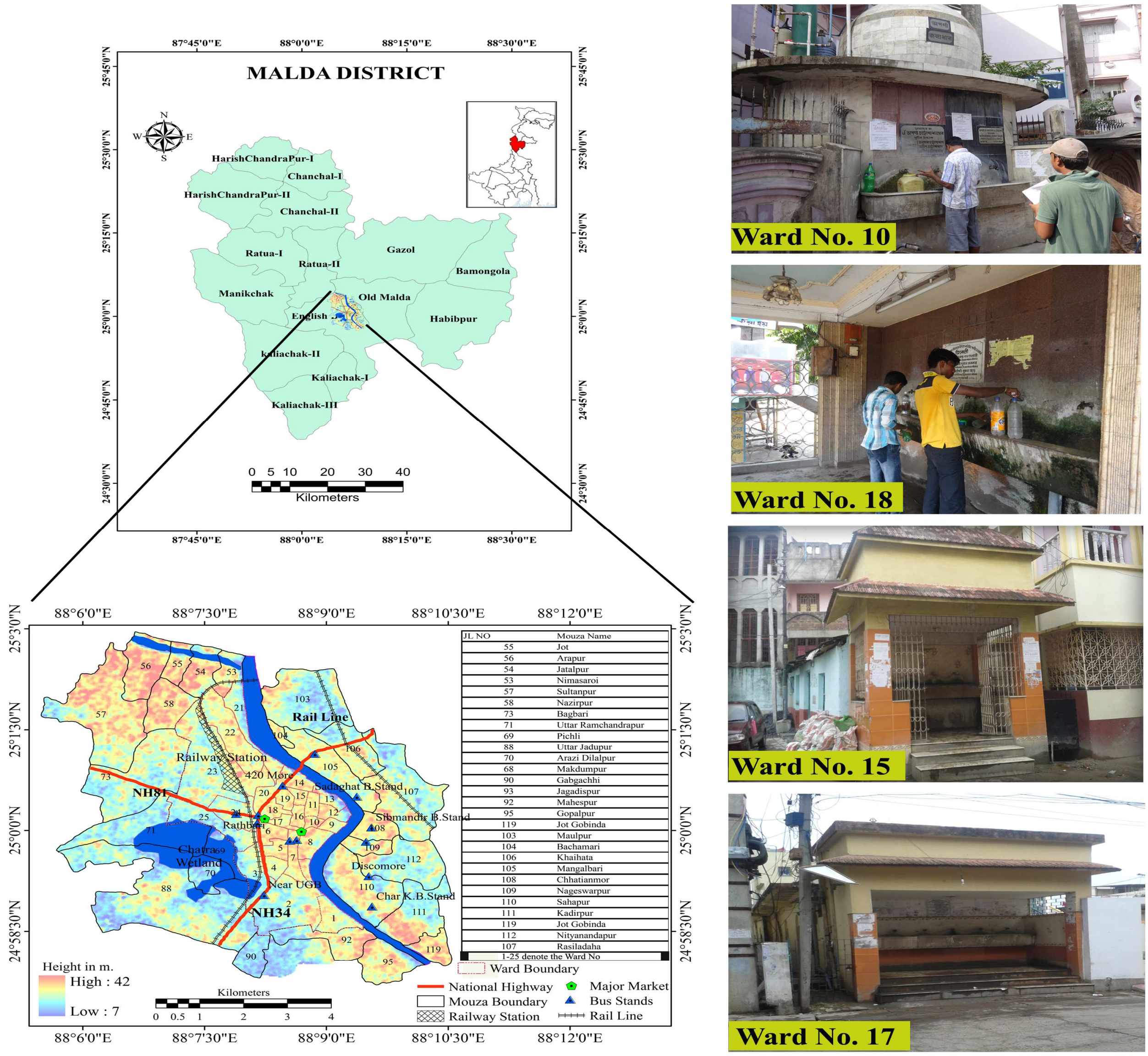

Fig. 1. Study area showing elevation classes, major drainage features and road lines over different Mouzas. *Value within mouzas indicate jurisdiction number (JL.No.), photographs are showing the nature of Jaladhar (water service centres) in different parts of the study area.*

3. MATERIALS AND METHODS

3.1. Methods for individual data layer preparation

For finding out suitable sites for installing new water service centre, six data layers have been used and out of these, four point based data layers namely centroid of the ward/mouzas; the existing water service centre, the public service centre, the location of bus stands are prepared based on the GPS survey data. These point data have been separately put in the feature class and distance maps have been prepared accordingly. The land use land cover map has been prepared from Landsat images (specification is listed in table 1) following supervised classification techniques. Population density DEM has been created based on population density of 125 micro-spatial units of 29 wards.

Table 1. Selected parameters and associated sources of data.

Name of the parameters	Sources
Centroid of the Ward / mouzas	With the help of Map in GIS environment
Existing water supply centres	Primary GPS survey
Public service centres	Primary GPS survey
Population density DEM	Census Data, 2011
Location of Bus stand	Primary GPS survey
Land use	Landsat Oli Image, 2014, Path/Row-139/43, Band used: G, R, NIR; Spatial resolution: 30 m.), Land use map, 2014 of Land reform dept., West Bengal

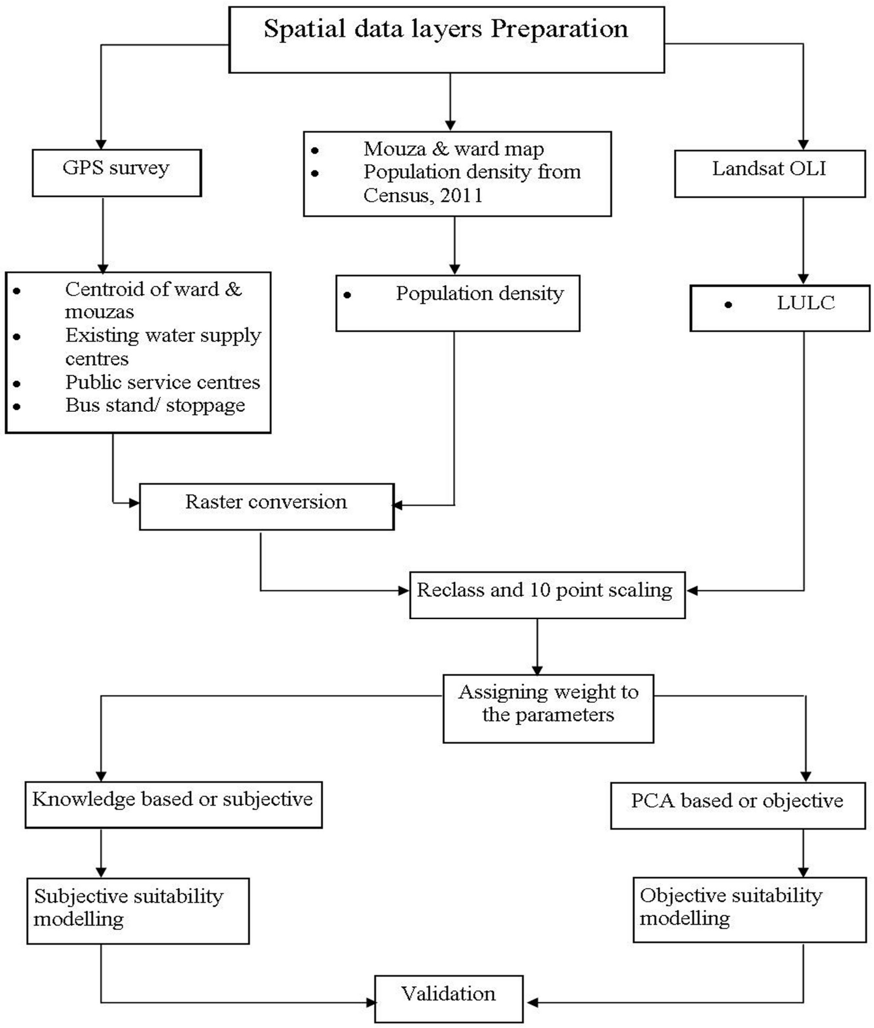

Fig. 2. Flow chart showing methodological brief in different stages.

3.2. Methods for data layer compositing

In last 30 years, a number of multi-attribute (or multi-criteria) evaluation procedures have been executed in GIS environment specially for land suitability appraisal, including WLC and its variants [15], [16] and the analytic hierarchy process (AHP) [17].

There are two elementary categories of multi-criteria appraisal methods in GIS: (1) the Boolean overlay operations (non-compensatory combination rules) and (2) the weighted linear combination (WLC) methods (compensatory combination rules). They have been the most habitually used approaches for diverse sorts of land-use suitability analysis [18], [19], [20], [21], and

[22]. These ways can be generalized within the structure of the ordered weighted averaging (OWA) [23], [24], [7], [22] and [25].

The WLC is a simple additive weighting based on the notion of a weighted average [26]. The concern decision architect in straight forward manner assigns weights of 'relative importance' to every attribute data layers. A total score is then calculated for each alternative by multiplying the relative weight defined for each attribute by the ranked value of each attribute sub class. After completing this process for all the attributes, the products are summed up. OWA is a familiar member of multi-criteria compositing family [38]. It includes two sets of weights: (1) the weights of comparative criterion importance and (2) the order (or OWA) weights. Although OWA is a comparatively newer method in multi-criteria family [38], there have been several implications of this approach in the GIS field [23], [24], [27], [28], [22], [14], [29], [7], [30] and [31]. All those applications use the conventional (quantitative) OWA. Particularly, research into GIS, OWA has thus far highlighted on the procedures that require quantitative specification of the attribute layers associated with the OWA operators.

In this study, WCL is used for compositing data layers, but weight has been assigned both subjectively and objectively and thus constructed two separate suitability models. This sort of modelling has been done for assessing the degree of difference between subjective and objective models.

In the present study, six parameters with proper database have been selected as map layers, as follows: 1) centroid of the ward /mouzas, 2) existing water supply centres, 3) public service centres, 4) population density DEM, 5) location of Bus stand and 6) land use/ land cover map. This process was carried out on the basis of raster based weighted linear combination and vector layers have been converted into raster layers using either distance/proximity mapping techniques using spatial analyst tool in Arc GIS software or lattice based raster plane like DEM in ERDAS Imagine software. Each attribute (map layer) is categorised into 10 classes ranking from 1 to 10 (adopting 10 point scale) assuming the fact that the higher rank value will reflect greater potentiality of proposed water service centres. To fulfil this purpose, all the attributes have been reclassified into 10 classes and ranked accordingly. The logic behind ranking to intra-attribute classes from 1-10 is described in table 2. Rank of all sub-classes under each attribute is then multiplied by the defined weight of each individual attribute.

In the introduction part, it is mentioned that weighted compositing will be done using both subjective and objective weighting method.

In case of subjective weighted compositing method, the weight of each attribute has been assigned subjectively considering the role of those in the study area following knowledge based method of weighting of [32], [33], [34], and [35] [36]. The total considered weight in this work is supposed to 1.

In case of objective WLC, weight has been calculated based on PCA centric correlation matrix following equation 1.

$$w_j = \frac{\sum rj}{\sum r} \qquad \text{(eq. 1)}$$

where:

rj = correlation of *j^th^* parameter with others,

$\sum r$ = sum of correlation value of all parameters, *wj* = weight of *j^th^* attribute.

This weighted linear combination has been done using raster calculator tool in Arc GIS environment. The function behind this is mentioned in equation 2.

$$\text{WLC=} \sum_{j=1}^{n} a_{ij} w_j \qquad \text{(eq. 2)}$$

where:

aij = i^{th} rank of j^{th} attribute.

The detailed methodological flow for carring out these modelling has been depicted in figure 2.

3.3. Logic behind subjective weight distribution

The centroid is considered as the most accessible point in term of distance. Hence the centroid of the ward has been selected as an important parameter.

If the existing water supply centre could be traced, the areas that are beyond the coverage of existing water supply centre, and where no water supply centre exists, can be identified. Thus, the location of existing water supply centre was identified through primary GPS survey and we created a layer in Arc GIS.

The public service centre is another important parameter of this work. As we know, ‘public service centres are considered areas mostly determining gathering. Being a gathering area, the drinking water demand is also quite high. Therefore, keeping that in mind, the GCP of public service centre of the study area was identified through the primary GPS survey and we created a layer as the above layer in Arc GIS. It is a common phenomenon that where the population density is high, the demand of purified drinking water will be also high. Therefore population density was calculated for each ward and mouzas of the study area. Behind the selection of this parameter, the logic is that the bus stand is considered as the junction point of the people gathering, where the drinking water demand is high. Through the land use map, the different land use category can be identified, among them: the built up area, where the demand of drinking water supply is relatively high. This is why this parameter was also selected for this study.

Table 2. Selected parameters, hierarchical ranking, and respective attribute weight.

Name of the attribute (j)	Highest rank indicates at 10 point scale (i)	Logic behind	Attribute weight age (wj) (Σwj = 1)	Attribute weight age (based on objective judgement)
1) Centroid of the ward / mouzas	10 rank at near the Centroids	Centroid considered as most accessible area to all who lives there	0.1	0.1
2) Existing water supply centres	10 rank at away from the existing supply centres	Demand for water point is high away from the existing service centres	0.2	0.2
3) Public service centres	10 rank at near the public service centres	Public gathering is high in these places specially during working hours	0.1	0.2
4) Population density DEM	10 rank at more density area	Demand is high in the densely populated area	0.3	0.2
5) Location of bus stand	10 rank at near the bus stand	People gathering is high in these bus terminus	0.2	0.2
6) Land use/ land cover map	10 rank at built up area	Demand is high in the built up area where people live	0.1	0.1

4. RESULTS AND ANALYSIS

4.1. Status of individual parameters

In case of centroid of the wards, most of the centroids are concentrated within the central part of the municipality (Fig. 3), where most of the existing water supply centres are located (Fig. 4).

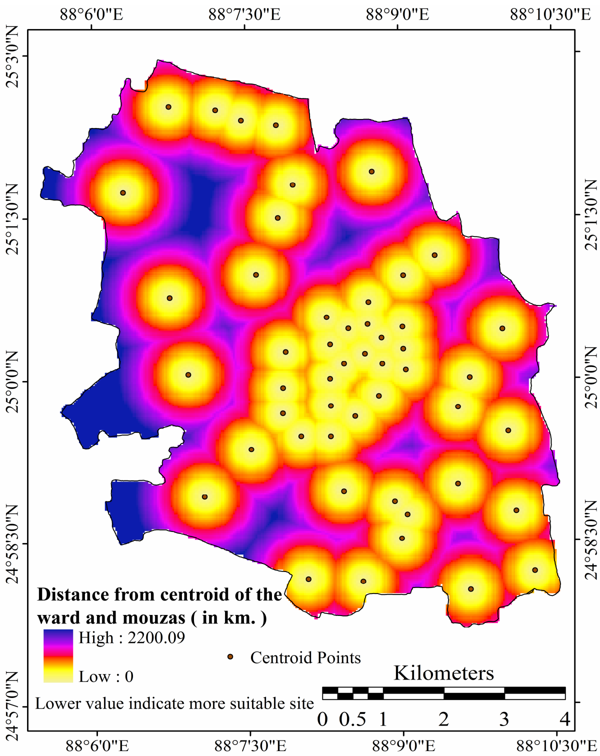

Fig. 3. Centroid of wards & mouzas.

Figures 5 and 6 show that public service centres are well distributed in the municipal area and major bus stands are mainly located alongside the major road axes such as NH 34, Gour Road, as earlier mentioned in Figure 1.

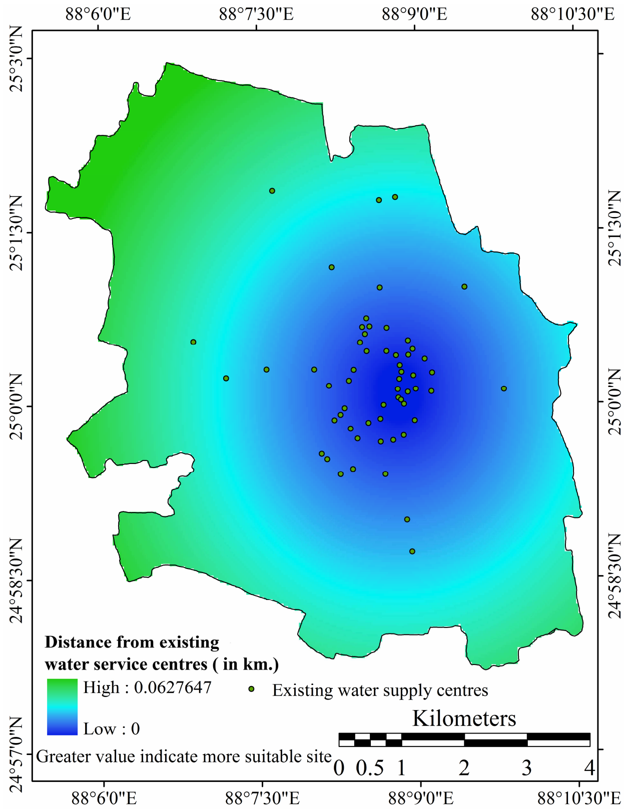

Fig. 4. Existing water supply centres.

Population density is of about 50,000 inhab./sq.km in the central part of the town, mainly between the Mahananda river and the Gour Road (Fig. 7). Land use land cover map in figure 8 shows that density of built up area is at maximum in the central part of the main town, where the population density is also high. The growth of high buildings in the central part, encroachment of settlement toward the wetland part as indicated in figure 8 are some notable characteristics in land use land cover scenario.

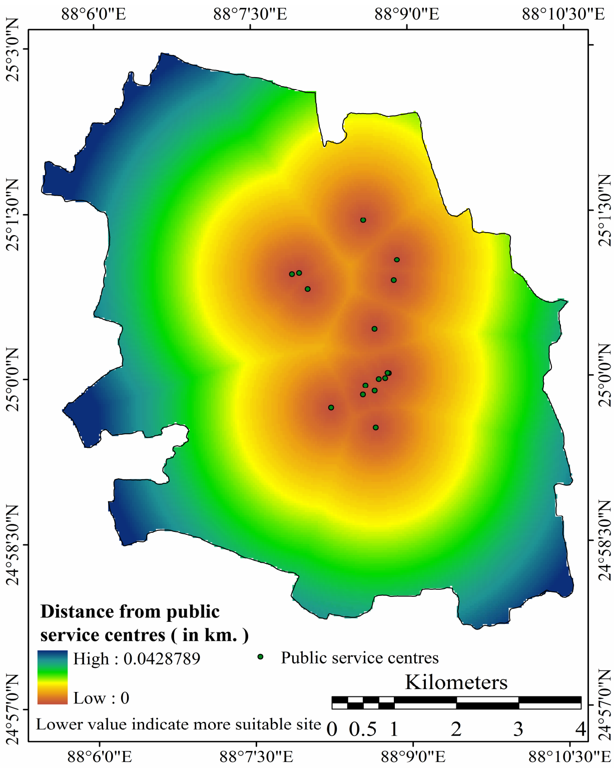

Fig. 5. Public service centres.

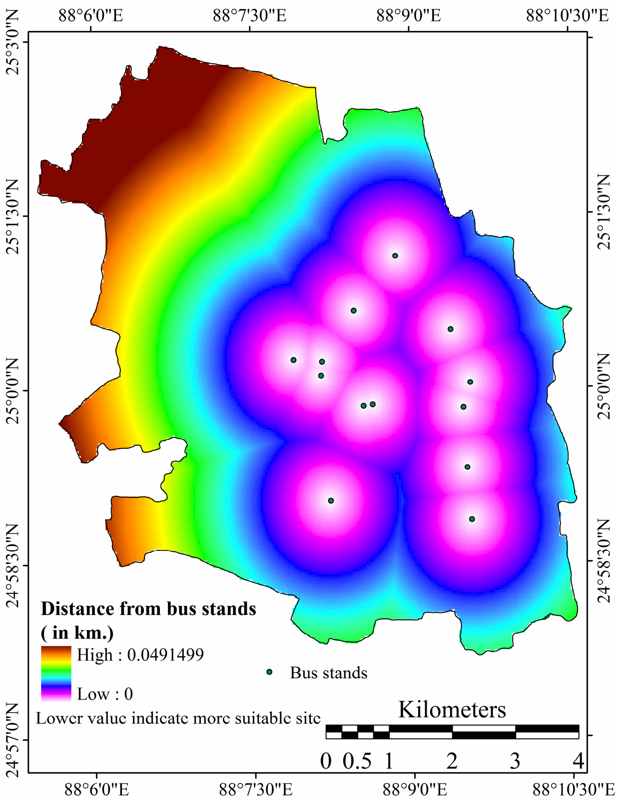

Fig. 6. Bus stands.

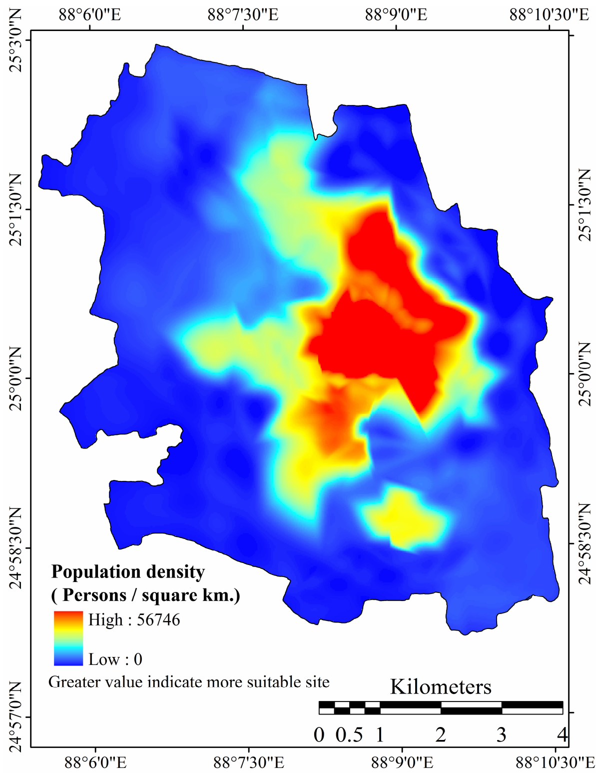

Fig. 7. Population density.

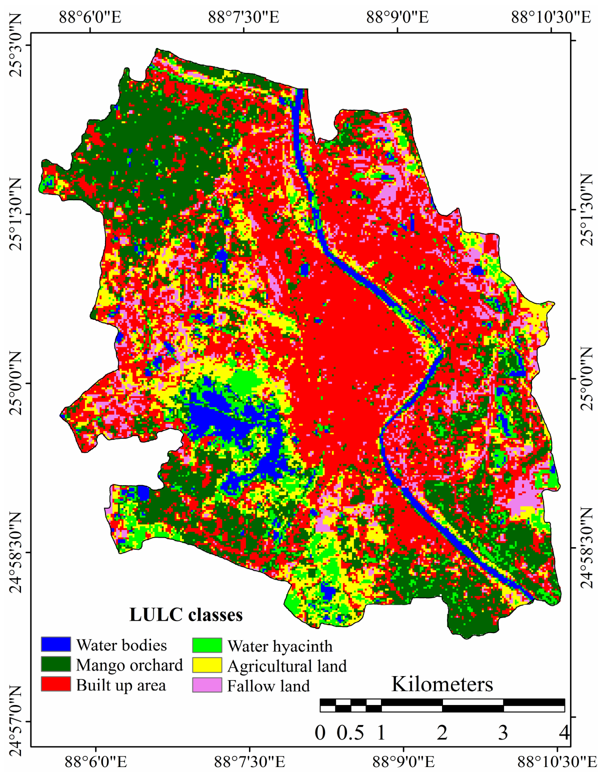

Fig. 8. Land use and land cover.

4.2. Compositing parameters and suitability analysis

From both the composite models for suitable sites constructed by using subjective and objective weighting methods, it is found that out of total study area (5,465.43ha.), 27.60% and 38.15% of area were delimited as highly suitable zones for installing new water service centres. It does mean that this area highly claims for more water service centres and therefore, while new service centres will be installed, it should be within the defined zones as shown in figures 9 and 10. Within total area under suitable class, for the convenience of prioritizing the distribution of limited number of sanctioned Jaladhars, this area is again subdivided into five classes and assigned priority ranking accordingly.

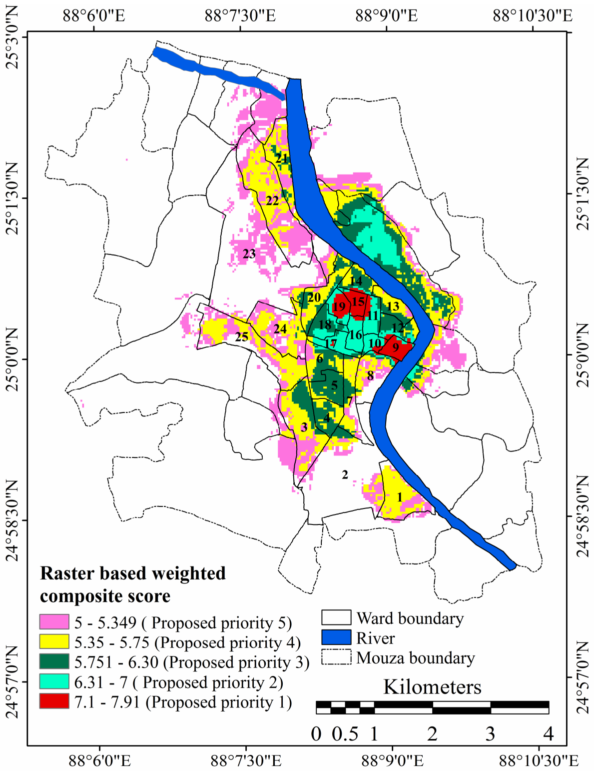

Fig. 9. Proposed area for installing new water service centre (based on subjective weight).

The proposed priority 1 indicates the degree of urgency for Jaladhar, which is greater than proposed priority 2, than priority 3, etc. Table 3 and 4 depict the areas under different priority classes within most suitable class of subjective and objective weight-based suitability models. Out of the total area, 3.05% and 4.68% areas for subjective and objective weighted composite models can strongly be emphasized for suggesting urgent basis installation of new water service centres followed by 2nd priority zones, which cover an area of about 8.51% and 4.29% in same manner (table 3 and 4). Ward number 9, 15 and 16 come under the zone of proposed priority 1 and therefore, they are in high demand for water service centres. Some northern parts of the study area are newly incorporated within municipal territory and few patches have found in high demand for Jaladhar. Table 5 characterizes the different proposed priority zones with their status in terms of individual parameters. In the proposed priority zone 1, seven centroids of the wards, nine existing water service centres, two public service centres, and one bus stoppage are existing and population density is of 54398/sq.km. Due to such dense population, demand for water is automatically high.

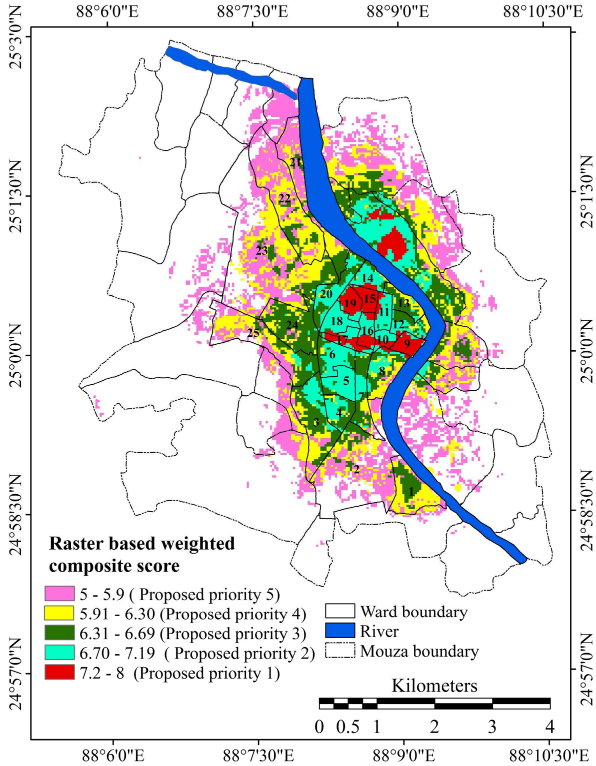

Fig. 10. Proposed area for installing new water service centre (based on objective weight).

Secondly, we aimed to compare the results that will be yielded from subjective and objective weighted compositing models. From these models, it was found that weighting pattern in case of objective weighting is quite similar as described in table 2. The only detected difference was in the case of population density. Knowledge-based weight for population density was 0.3 out of 1 but as per the objective weighting, this parameter received 0.2. Pair wise importance analysis and weighting of parameters could perhaps encourage us to assign more weight to the population density than to the public service centres or bus stands as it is done in knowledge-based weighting. It can then be inferred that knowledge-based model is valid and it is based on quite strong foundation. Such model can also help to avoid a good number of errors. The total selected area mostly demanding water service centres is of 1508.54 ha and of 2085 ha for these models. There is no significant difference between the identified area (subjective: 3.05% and objective: 4.68%) within the proposed priority 1 (see table 3 and 4). The positional accuracy of the priority zones is also high (see Fig. 9 and 10).

Thus, it can be concluded that if sufficient knowledge about the parameters is available, knowledge-based weighted compositing can be carried out. Table 6 represents the Pearson's product moment correlation coefficient between knowledge-based composite model and the separately selected parameters. Multi-directional relation is found, as per their nature, influence toward the objective. For example, r value is -0.46056, meaning that demand for water is relatively low. Population density is positively and strongly correlated (r=0.62606) with high water demanding areas.

Table 3. Suitability classes and their respective pixel and area (based on subjective judgement).

Range of the suitability class	Proposed priority	No. of pixel	Area in ha	Area in percentage
5 – 5.349	5	9450	850.5	65.9824
5.35 – 5.75	4	2223	200.07	15.52158
5.751 – 6.30	3	1219	109.71	8.511381
6.31 - 7	2	992	89.28	6.926407
>7	1	438	39.42	3.058232

Table 4. Suitability classes and their respective pixel and area (based on objective judgement).

Range of the suitability class	Proposed priority	No. of pixel	Area in ha	Area in percentage
5 – 5.9	5	11432	1531.88	73.68
5.91-6.30	4	1702	228.07	10.96
6.31-6.69	3	666	89.24	4.29
6,7	2	989	132.52	6.37
>7	1	727	97.42	4.68

Table 5. Characteristics of Suitability classes in terms of individual parameters.

Suitability class	Parameters					
	Centroid of the Ward & Mouzas	Existing water supply centres	Public service centres	Bus stands/Stoppage	Population density (person/sq.km.)	Land use & land cover
5	4	10	4	3	13148	Built up, fallow land &agricultural land
4	4	16	4	5	17648	Built up, Fallow land
3	6	22	4	3	27731	Built up area
2	8	10	1	2	40082	Built up area
1	7	9	2	1	54398	Built up area

Table 6. Factorial priority of the selected parameters.

Parameters	Correlation value (Subjective)	Correlation value (Objective)	Parameters	Correlation value (Subjective)	Correlation value (Objective)
Centroid of the ward & mouzas	-0.37316	-0.48177	Bus stands/ stoppage	-0.33398	-0.75278
Existing water service centres	-0.48056	-0.82982	Population density	0.62606	0.79149
Public service centres	-0.6131	-0.87534	Land use & land cover	-0.02394	0.02984

4.3. Validation of suitability models

For validating the composite suitability models, a primary survey has been conducted in search of whether there is any need of installing extra water service centres in different priority zones. Table 7 depicts the selected wards (spatial administrative units within municipal areas) in different priority zones where the primary survey was conducted. Table 8 demonstrates the responses of the concerned respondents regarding the urgency of installing new service centres. From this table it is revealed that in the case of the ward no. 15, located on priority zone 1, about 65% people show high urgency for being stakeholders of few new water service centres. Out of the total number of respondents (50 individuals) 95% of them, irrespective of class and creed, expressed their view toward installing more centres. Even people in the service sector, sometimes self-sufficient in terms of acquiring safe water either through setting pumping machinery and putting aqua guards, showed their concern, feeling the need of the general people.

The demand supply ratio of water in different priority zones is also calculated for supporting the models. Per capita average water use in 2016 is of 59.75 l/day. In high priority zone, per capita water use is slightly less (53.23litre/day) than the average water use. This is perhaps another support to the constructed models. The calculated demand supply gap in high priority zone is of more than 25% (296,541 l/day) which is excessively high. Consequently, it can be inferred that the constructed models are valid.

Table 7. Selection of wards in different priority zones and number of observations.

Priority Zone	Ward No.	Time duration	No. of observation
1	15		50
2	10		50
3	20	30 Minute	50
4	18		50
5	8		50

Table 8. Nature and distribution of respondents by professions and their response against the question whether new water service centre is required (value within parenthesis indicates priority rank).

Ward No (Priority rank)	No of respondent By profession							Response against the question whether new WSC is required			
								Yes			No (%)
	Business	Labourer	Service	Student	Toto driver	Daily migrants	Total	Highly Essential (%)	Essential (%)	Good if installs (%)	
15 (1)	10	20	5	10	5	-	50	65	25	5	5
10 (2)	23	5	6	4	2	10	50	53	27	10	10
20 (3)	22	9	3	-	3	13	50	58	24	11	7
18 (4)	18	1	11	3	4	13	50	50	15	18	17
8 (5)	19	6	15	-	2	8	50	55	19	14	12

5. CONCLUSION

If a higher number of data layers were employed in this model, it would be more comprehensive. This can be seen as one of the limitation of this work. But being a part of this town, authors found logical base of the models. The identified areas are really running under difficulties in terms of availability and accessibility of water service centers. Middle class people are more dependent on this service for getting safe drinking water to avoid extra cost for water that would be paid if water was purchased from any other branded water supplying companies. Considering all these facts, smooth performances and equipped distribution of water is highly essential for enhancing public support system from Government's part. It is also to be mentioned that these models are time dependent as the factors considered here are dynamic. Therefore, timely review and reconstitution of models in this regard will provide decision support for the reorientation of the plan.

REFERENCES

[1] **Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., et al** (2010), *Global threats to human water security and river biodiversity*. Nature, vol. 467, pp. 555-561.

[2] **UNESCO** (2009), *Water in a changing world*. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr3-2009/downloads-wwdr3/

[3] **Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., et al** (2010), *Water Supply and Sanitation Collaborative Council*: Annual Report 2010.

[4] **Rajmohan, N., Prathapar, S. A.** (2014), *Extent of arsenic contamination and its impact on the food chain and human health in the eastern Ganges Basin: a review. Colombo, Sri Lanka:* International Water Management Institute (IWMI). 47 p. (IWMI Working Paper 161). doi: 10.5337/2014.224

[5] **UNESCO** (2012), *UN world water development report*, 4th ed. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/#c219661

[6] **UNICEF**, **World Health Organization** (2013), *Progress on drinking water and sanitation 2012 update*. New York. http://www.wssinfo.org/

[7] **Makropoulos, C., Butler, D.** (2005), *Spatial ordered weighted averaging: incorporating spatially variable attitude towards risk in spatial multi-criteria decision-making*, Environ. Modell. Software vol. 21 issue 1, pp. 69-84.

[8] **Yager, R. R.** (1988), *On ordered weighted averaging aggregation operators in multi-criteria decision making*. IEEE Trans. Syst. Man Cybernet. 18.

[9] **United Nations** (2000), *Charting the progress ofpopulations*.http://www.un.org/esa/population/publications/charting/contents.htm

[10] **Bogardi, J. J., Dudgeon, D., Lawford, R., Flinkerbusch, E., Meyn, A., Pahl-Wost, C., Vielhauer, K., Vorosmarty, C**. (2012), *Water security for a planet under pressure: interconnected challenges of a changing world call for sustainable solutions. Current Opinion*, In Environmental Sustainability 2011, vol. 4, pp. 1-9.

[11] **Chandrashekaram, D.** (2010), *Scenario of arsenic pollution in ground water: West Bengal,* Geology in China, vol. 37, issue 3, pp. 712-723

[12] **Chakraborty, D., Das, D., Sumanta, B. K.** (1996), *Arsenic in groundwater in six districts of West Bengal, India,* Journal of Environmental Geochemistry and Health, vol. 18, pp. 5-15.

[13] **U.N.** (2006), *African water development report 2006*. UN-Water/ Africa, Addis Ababa, Ethiopia, 370 pp.

[14] **Rashed, T., Weeks, J.** (2003), *Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas*. Int. J. Geogr. Inform. Sci., vol. 17, issue 6, pp. 547-576.

[15] **Carver, S. J.** (1991), *Integrating multi-criteria evaluation with geographical information systems*, International Journal of Geographical Information Systems, vol. 5, issue 3, pp. 321-339.

[16] **Eastman, J. R.** (1997), *Idrisi for Windows, Version 2.0: Tutorial Exercises, Graduate School of Geography—Clark University*, Worcester, MA.

[17] **Banai, R.** (1993), *Fuzziness in geographic information systems: contributions from the analytic hierarchy process*. International J. Geogr. Inform. Syst., Vol. 7, issue 4, pp. 315–329.

[18] **Heywood, I., Oliver, J., Tomlinson, S.** (1995), Building *an exploratory multi-criteria modelling environment for spatial decision support*. In: Fisher, P. (Ed.), Innovations in GIS, vol. 2, pp. 127-136.

[19] **Jankowski, P.** (1995), *Integrating geographical information systems and multiple criteria decision making methods*. International J. Geogr. Inform. Syst., vol. 9, issue 3, pp. 251-273.

[20] **Barredo, J. I., Benavidesz, A., Hervhl, J., van Westen, C. J.** (2000), *Comparing heuristic landslide hazard assessment techniques using GIS in the Tirajana basin, Gran Canaria Island,Spain*. International J. Appl. Earth Observ. Geoinform., vol. 2, issue 1, pp. 9-23.

[21] **Beedasy, J., Whyatt, D.** (1999), *Diverting the tourists: aspatial decisionsupport system for ourism planning on a developing island*. J. Appl. Earth Observ. Geoinform., vol. 3 issue 4, pp. 163-174.

[22] **Malczewski, J., Chapman, T., Flegel, C., Walters, D., Shrubsole, D., Healy, M. A.** (2003), *GIS-multicriteria evaluation with ordered weighted averaging (OWA): case study of developing watershed management strategies*. Environ. Plann, vol. 35, issue 10, pp. 1769-1784.

[23] **Asproth, V., Holmberg, S. C., Hakansson, A**. (1999), *Decision Support for spatial planning and management of human settlements*. In: International Institute for Advanced Studies in Systems Research and Cybernetics. In: Lasker, G.E. (Ed.), Advances in Support Systems Research, vol. 5, pp. 30-39.

[24] **Jiang, H., Eastman, J. R.** (2000), *Application of fuzzy measures in multi-criteria evaluation in GIS*. Int. J. Geogr. Inform. Syst., vol. 14, pp. 173-184.

[25] **Malczewski, J., Rinner, C.** (2005), *Exploring multicriteria decision strategies in GIS with linguistic quantifiers: a case study of residential quality evaluation*. J. Geogr. Syst., vol. 7, issue 2, pp. 249–268.

[26] **Eastman, J. R.** (2006), *Idrisi andes: tutorial, clark labs*. Clark University, Worcester Engineering, vol. 7, issue 5, pp. 346-55.

[27] **Mendes, J. F. G., Motizuki, W. S.** (2001), *Urban quality of life evaluation scenarios: The case of Sa˜o Carlos in Brazil.* CTBUH Rev., vol. 1, issue 2, pp. 1-10.

[28] **Araujo, C. C., Macedo, A. B.** (2002), *Multicriteria geologic data analysis for mineral favorability mapping: application to a metal sulphide mineralized area, Ribeira valley metallogenic province Brazil.* Nat Resour Res, vol. 11, pp. 29-43.

[29] **Calijuri, M. L., Marques, E. T., Lorentz, J. F., Azevedo, R. F., Carvalho, C. A. B.** (2004), *Multi-criteria analysis for the identification of waste disposal areas*, Geotech. Geol. Eng., vol. 22, issue 2, pp. 299-312.

[30] **Rinner, C., Malczewski, J.** (2002), *Web-enabled spatial decision analysis using ordered weighted averaging*. J. Geogr. Syst., vol. 4, issue 4, pp. 385-403.

[31] **Malczewski, J.** (2004), *GIS-based land-use suitability analysis: a critical overview*, Progr. Plann., vol. 62, issue 1, pp. 3-65.

[32] **Islam, M. M., Sado, K.** (2002), *Development of priority map flood countermeasures by remote sensing data with geographic information system*. Journal of Hydrologic.

[33] **Sanyal, J., Lu, X. X.** (2006), *GIS-base flood hazard mapping at different administrative scales: a case study in Gangetic West Bengal, India*. Singap J Trop Geogr., vol. 27, pp. 207-220.

[34] **Drobne, S., Lisec, L**. (2009), *Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging*, Informatica, vol. 33 issue 4, pp. 459-474.

[35] **Mandal, D., Pal, S.** (2015), *A multi-parametric spatial modeling of vulnerability due to arsenic pollution in Murshidabad district of West Bengal, India*. Arabian Journal of Geosciences, pp. 1-8.

[36] **Pal, S.** (2016), *Identification of Soil Erosion Vulnerable Areas in Chandrabhaga River Basin: a Multi-criteria Decision Approach*, Model. Earth Syst. Environ, vol. 2 issue 5, pp.1-11.