Use of the Suitability Model to Identify Landfill Sites in Lahore-Pakistan

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Abstract: Site selection is a vital and basic concern of solid waste management in Lahore District, Pakistan, where there is fast growing urbanization. An appropriate landfill site for management of solid waste in this district must be found, and this demands the evaluation of multiple suitability criteria. Based on the current situation of the study area, these criteria were assigned weights according to their relative importance by using the analytical hierarchy process (AHP). The weights were then used in a simple additive weighted process (SAW) to generate a hierarchy of suitable sites for landfill to resolve the solid waste issue in Lahore District. Geographic information system (GIS) environment was used to collect, manipulate, analyze and present spatial data. Each spatial characteristic was standardized to same scale of 1 to 5 where 1 is the lowest suitability and 5 is highest suitability. This work presents a GIS-based site selection methodology that provides support to decision makers for the assessment of waste management issues in Lahore District.

Keyword: Site Selection, Simple Additive Weight, Landfill, Solid Waste, Spatial, Lahore.

INTRODUCTION

Solid waste management is a serious problem in Lahore District with respect to suitable urban planning. Dumping these wastes inappropriately will cause environmental, social, economic and ecological issues in the study area. As the population increases and the district becomes rapidly urbanized, more people are wishing to live here. This population growth creates a directly proportional increase in the amount of daily waste generated. Unfortunately more and more waste is generated every day, making its management a difficult problem owing to the lack of availability of a final disposal site. Suitable planning is therefore required to minimize the impact caused by the current situation in Lahore district. The general goal of this study was to identify those areas which are feasible for a landfill site, using an integration of GIS and Weighting method [1-4]. GIS is an intelligent system providing more realistic analysis and models based on different criteria to convert spatial and non-spatial data into useful information which helps the decision maker to make critical decisions for landfill site selection.

Study Area

Lahore is one of the most enticing districts of Pakistan, situated between 74° 10' and 74° 39' East longitude and 31° 15' and 31° 43' North latitude as shown in Figure **1**. It covers an area of 1,772 square kilometers and, according to the 2013 estimates, the population in Lahore district was 12 218 345, of which 81.17% were urban dwellers. In this district alone, around 5000 tons of waste is produced daily, but the essential issue here is the non-accessibility of the final disposal site. Hence, this district confronts a major issue of waste management.

MATERIALS AND METHODS

Suitability criteria analysis was performed to identify suitable sites for landfill in the GIS environment using Arc GIS 10.2 and its spatial extensions. A suitability analysis considered all the provided criteria for siting a landfill. Some of the data were obtained as analog maps. These raster data were converted into the vector shape files for further analysis by establishing a geographic database to extract useful information. All information was projected into WGS_1984.

A set of six criteria for landfill site selection was developed thorough a literature review while considering economic, social and environmental parameters [2, 5-8].

Six input digital map layers including surface water, slope, road, ground water, land use, and soil types were prepared and multi criteria analysis were implemented with geographical information system. Soil type were ranked according to their porosity and urban areas where there is no soil are consider least suitable for siting any landfill site. In the study area, there are different types land uses (see Table **1**. Land use types were ranked according to their suitability for a landfill site as least suitable to most suitable for a landfill site by assigning values 1 to 5. All the raster had

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ISSN: 1814-8085 / E-ISSN: 1927-5129/16

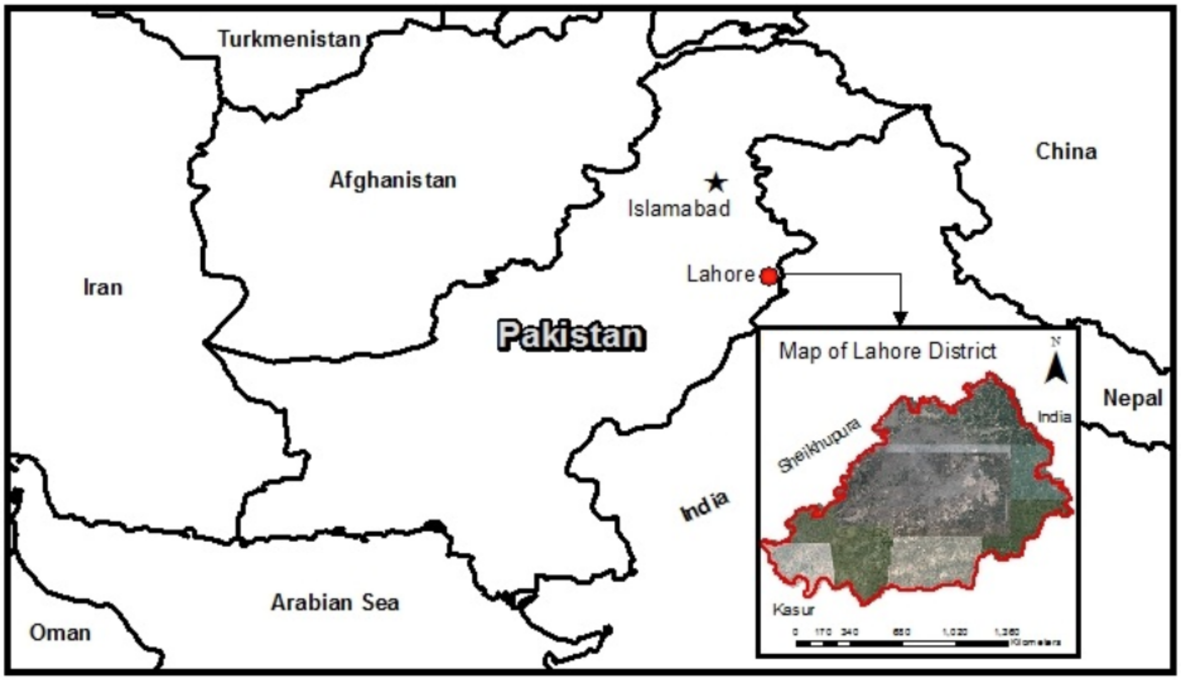

Figure 1: Map showing the study location.

different cell values, so for suitability analysis it was necessary to standardize all the data to a common scale by ranging between the scale of 1 to 5, where a score of 1 indicated least suitable and a score of 5 indicated most suitable, as shown in Table **1**.

Weighting is a method for using raster data to express the relative significance. It is generally unsatisfactory to give all the criteria equal importance irrespective of their relative significance. But as these are different criteria, it is difficult to prioritize them rationally. Consequently, Analytical Hierarchy Process (AHP) [9] was used in this study as tool to consider these convoluted issues of site selection. As AHP gives more exact and good relational representation among different criteria [10, 11]. This mathematical process provided information on relative importance and preferences to synthesize the information (including consistency checking) and provide a priority ranking of all alternatives in terms of their overall preference. The weights of a particular criterion are built up by ranking them on a scale of 1 to 5 and assigned value of zero for restricted cells which could not participating for final selection on the basis of their significance and suitability. Each input raster is weighted according to its importance or its percent influence. The weight is a relative percentage, and the sum of the percent influence weights must equal 100 (43+3+7+20+10+20= 100) as shown in Table **1**.

Table 1:

Layer/ Sub layers	Ranking	Weight (%)
Surface Water		43
≤200 m	1	
>200 m	5	
Slope		4
≤10 %	5	
>10 %	1	
Roads		3
≤300 m	5	
>300 m	1	
Ground Water		20
>5 m	5	
≤5 m	1	
Land Use		10
Water body/ River Land	1	
Built Up	2	
Park / Orchid	3	
Cultivated Land	4	
Open/ Barren Land	5	
Soil		20
River Bed/ Restricted Area	0	
Urban Area (No Soil)	1	
Loamy Sand	2	
Silt Loam	3	
Silty Clay Loam	4	
Loams/ Clay Loam	5	

To calculate suitability index (S), simple additive weighing (SAW) method was used. This method is widely used to calculate final suitability values in multiple criteria problems; the mathematical formulation of the method is described by [2]:

$$S = \sum_{i=1}^{n} WiXi$$

Where: S – suitability score

Xi – factor scores (cells)

Wi – weights assigned to each factor

For any site: S is the suitability index, Wi is the relative importance weight of the criterion i, Xi is the grading values of the area under criterion i, n is the total number of criteria.

RESULTS AND DISCUSSION

The suitability factor model is based on the weights and criteria of selected factors [1, 12, 13]. The researcher chose six factors for this model**.**

1. Surface Water

The landfill site should not be located within a surface water or water resource protection area so that surface water should not be contaminated by leaching. A weighting of 1 was then applied if ≤ 200 m away and 5 for >200 m away [10].

2. Slope

Ninety-six percent of the slopes in Lahore District fall within the range of 0–10%. According to [6] and [3], land with a slope less than 10% is highly suitable for waste dumping. Thus, considering these results and using geospatial techniques, most of the area was found to be suitable for a landfill site with respect to slope.

3. Roads Accessibility

A good network of roads to cover the transport distances from the source of waste generation to the final disposal station is economically desirable. A weighting of 1 was then applied if >300m away and 5 for ≤300m away.

4. Groundwater

Contaminations may leach through the soil and pollute the quality of fresh water. Fresh groundwater should be avoided or protected from leaching of landfill toxins. A weighting of 1 was then applied if ≤5m away and 5 for >5 m away [4].

5. Land Use

In the study area, there are different types of land use. Land use types were categorized by considering their suitability for a landfill site. For example, landfills may not be constructed on sites within a distance of less than 1000 m from an existing recreational area [11,14]. A new landfill should not be planned within 200m from the rivers or adjacent plains.

6. Soil

Soil type plays a vital role in the selection of landfill sites. The porosity of the soil controls the filtering speed and velocity for the groundwater flow. If the soil type is less porous then there is less chance of infiltration and leaching into the ground. Fine-grained soils like clay are more suitable for landfills than coarse-grained soils [15, 16].

The researcher adopted the pairwise comparison developed by [9], which deals with the pairwise comparison as input to yield a ratio matrix and produces relative weights as output. Numerous researchers have evaluated six criteria at a time according to their relative importance. Index values from 1 to 9 have been used where 9 is for most and 1 for least important. Then, the normalized principal eigenvector is used to calculate the criteria weights. Lastly a statistically reliable estimate (Consistency Ratio) of the resulting weights was introduced by prof. Saaty. If the value of consistency ration is less than or equal to 10% then the inconsistency is acceptable [9]. If the consistency ratio is greater than 10% then there is need to revise the judgment. In present study, the consistency ratio of the criteria comparison is determined, that is 7.96%.

As all the raster information used for this study has different formats, re-classification technique was used to change the value of input raster into new values based on the new information provided. As a result of it, particular values were grouped together into the same class and then reclassified into a common scale to standardize the data. These Standardized Classes are given a score on a scale of 1 to 5, where 5 represents the most important. Sites with less distance to major roads are more suitable for landfill and were assigned a value of 5, whereas sites with difficult roads

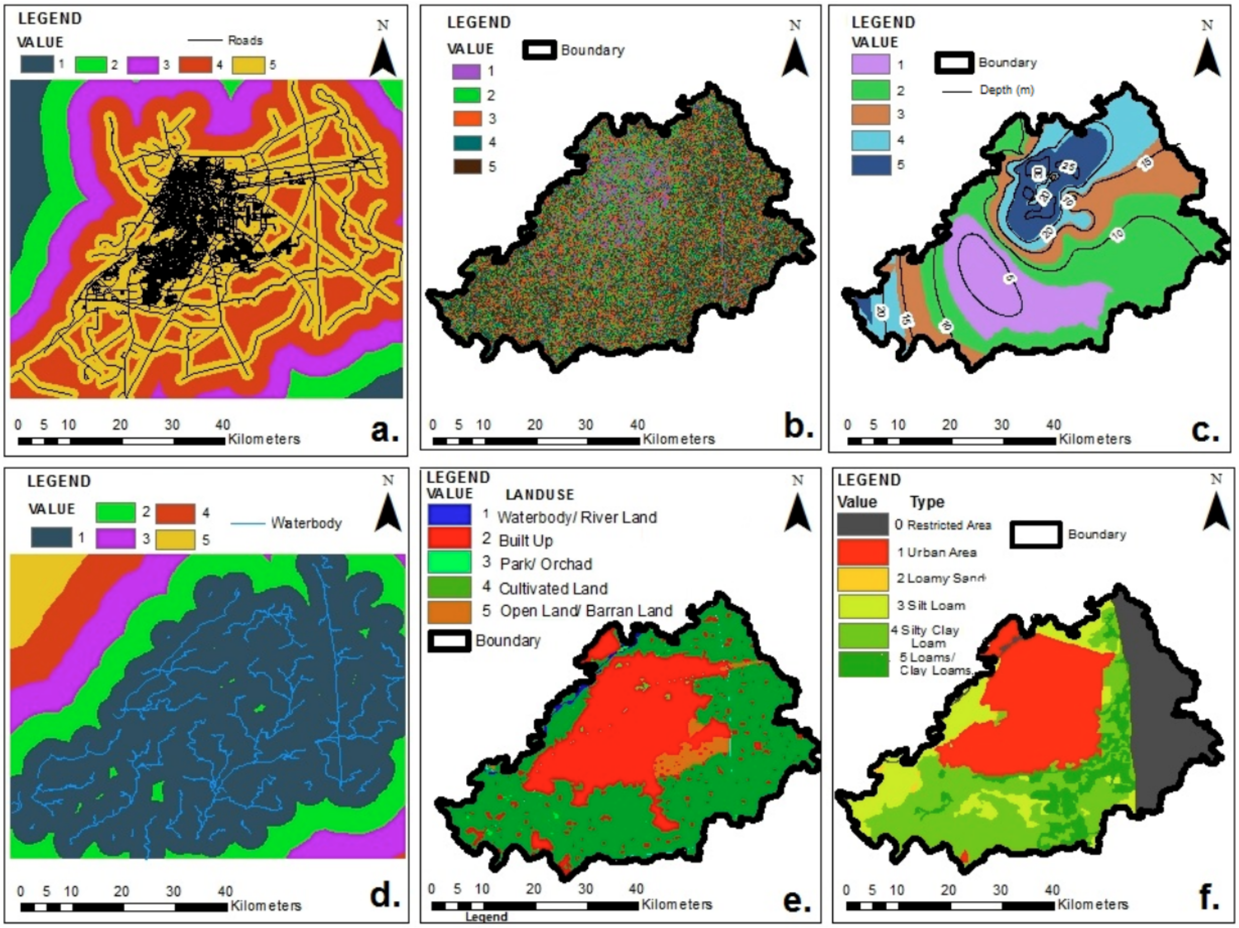

Figure 2: (**a**) Road suitability index, (**b**) slope of the land surface suitability index, (**c**) ground water suitability index (**d**) surface water bodies' suitability index, (**e**) land use suitability index, (**f**) soil suitability index.

accessibility are less suitable and assigned a lower value, as shown in Figure **2a**. Figure **2b** shows that the as much as the slope is steep value area is unsuitable for landfill so assign value of 1 but the value is 5 for less steeper or plain area because area with low slope is suitable to a landfill site. In Figure **2c**, the value 5 represents the lowest level of ground water and the value 1 represents the highest ground water level. Sites at greater distance from water bodies are more suitable for landfill and are assigned a value of 5, whereas those closer to water bodies are less suitable and assigned a lower value (Figure **2d**). For land use, open areas and barren land are more suitable than the urban areas. River or flood plains are not recommended for landfills. Parks and other recreations should not be disturbed by landfills [5], as shown in Figure **2e**. Figure **2f** shows the reclassification of soil based on textural type. Soil with a clay texture is most recommended, whereas sandy soil is less desirable for a landfill site [17].

Once the datasets had been reclassified, the simple additive weighing (SAW) method [12, 18] using weight overlay tools was used to generate a final suitability evaluation score for each cell. The mathematical formula is described by [2] as:

$$S = \left(W_{lu}C_{lu}.W_{w}C_{w}.W_{gw}C_{gw}.W_{s}C_{s}.W_{rd}C_{rd}.W_{Sl}C_{Sl}\right)$$

Where

W_{lu}& C_{lu} = Weight and Criteria for land use

W_{w}& C_{w} = Weight and Criteria for waterbodies

W_{gw}& C_{gw} = Weight and Criteria for ground water

W_{s}& C_{s} = Weight and Criteria for soil texture

W_{rd}& C_{rd} = Weight and Criteria for roads

W_{sl}& C_{sl} = Weight and Criteria for slope

The resulting cell values produced the final output raster and are displayed on a suitability factor map (Figure **3**), in which areas having a value of 5 (brown area on Figure **3**) are the most suitable areas and

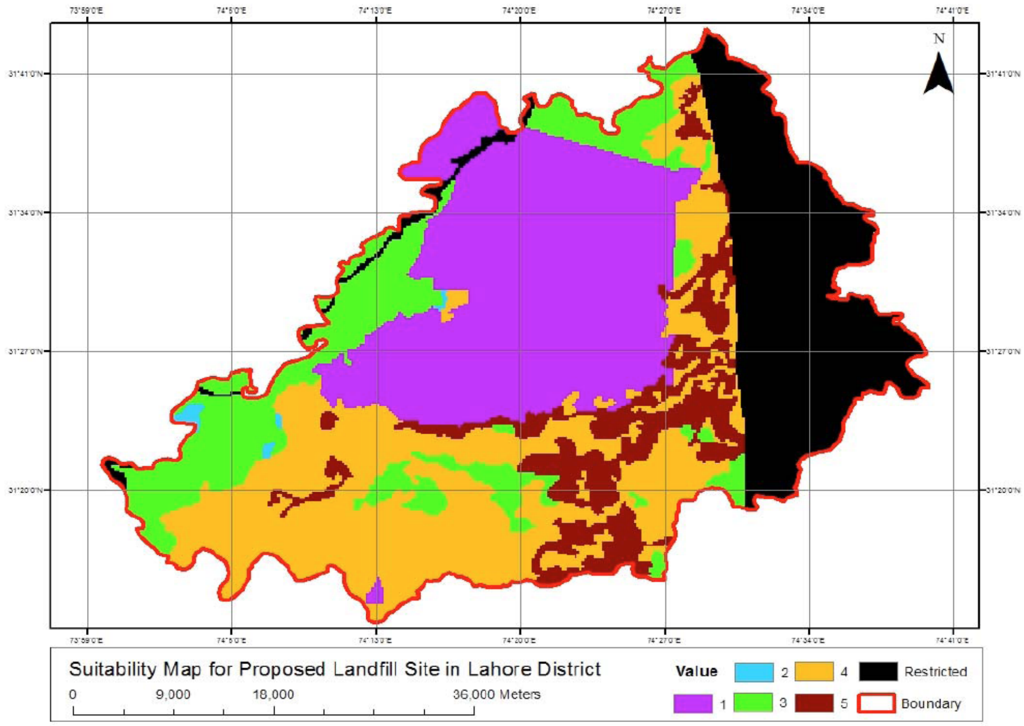

Figure 3: Landfill final suitability index map (Source: Rathore *et al*. 2015).

those with value of 1 (the purple areas) the least suitable areas for siting a landfill.

CONCLUSIONS

Site selection for landfill is a complicated process which includes assessing the various components like regulations, natural, environmental, socio-cultural and financial issues. GIS has the capability to manufacture useful maps to facilitate the rapid selection of a landfill site. The multiple criteria evaluation analysis also acts as a useful tool in making a decision for landfill site selection by presenting consistent ratings and weightings to the area. For that reason the integration of GIS and Simple Weighted Sum approach greatly facilitates decision-making. Different criteria are defined to select a suitable site for a landfill as per data availability and utilized as input map layers. Relative importance weights are assigned to all the factors using an Analytical Hierarchy process across the study area where scores for cells are the product of their standardized rating and assigned weight. This yields a multi-tiered situation which integrates information from the literature with local goals to create a map of situational weight-based sites for landfilling. In our study, the output maps were divided into 5 dataset classes ranging from unsuitable to the most suitable. The most suitable areas derived from the model corresponded to open land or barren areas that would entail minimal social, economic and environmental hazards; which is a key purpose of this study.

Some of the datasets, such as that for ground water raster (showing different water level) were not specifically prepared for the landfill site selection purpose, and the information provided from these maps was not quite satisfactory. The map was therefore generated by interpolation. It is clear that, rather than a general-purpose ground water hydrology map, the maps should show accurate depths, characteristics of the unconsolidated surficial deposits and their corresponding leaching effects. The slope was extracted on the basis of the available digital elevation model (DEM) so the slope layer needs to be refined by using a high resolution DEM. For future studies, it is recommended to include a DRASTIC model to estimate the leaching effect.

ACKNOWLEDGEMENT

The author is very grateful to the Punjab Soil Department, NESPAK, Lahore Development Authority and The Urban Unit for their support in providing required data.

REFERENCE

[1] Gbanie SP. Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision

Analysis (MCDA): Case study Bo, Southern Sierra Leone. Applied Geography 2012; 36: 3-12. http://dx.doi.org/10.1016/j.apgeog.2012.06.013

[2] Kontos TD, Komoilis DP, Hlvadakis CP. Siting MSW landfills on Lesvos Island with a GIS based methodology. Waste Management Research 2003; 21: 262-277. http://dx.doi.org/10.1177/0734242x0302100310

[3] Leao S, Bishop I, Evans D. Assessing the demand of solid waste disposal in urban region by urban dynamics modelling in a GIS environment. Resources, Conservation and Recycling 2001; 33: 289-313. http://dx.doi.org/10.1016/S0921-3449(01)00090-8

[4] Sumathi VR, Natesan U, Sarkar C. GIS-based approach for optimized siting of municipal solid waste landfill. Waste Management 2007; 28: 2146-2160. http://dx.doi.org/10.1016/j.wasman.2007.09.032

[5] Akbari V, Rajabi MA, Chavoshi SH, Shams R. Landfill site selection by combining GIS and Fuzzy Multi Criteria Decision Analysis, case study: Bandar Abbas, Iran. World Applied Sciences 2008; 3: 39-47.

[6] Sener S, Sener E, Nas B, Karagüzel R. Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Management 2010; 30: 2037-2046. http://dx.doi.org/10.1016/j.wasman.2010.05.024

[7] Nas B, Cay T, Iscan F. Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. Environmental Monitoring and Assessment 2009; 24(1): 491-500.

[8] Vasiljevic TZ, Srdjevic Z, Bajcetic R, Miloradov MV. GIS and the Analytic Hierarchy Process for regional landfill site selection in transitional countries: A case study from Serbia. Environmental Management 2011; 12(49): 445-458.

[9] Saaty T. The Analytical Hierarchy Process. New York: Mcgraw-Hill 1980.

[10] Elahi A, Samadyar H. Municipal Solid Waste Landfil Site Selection Using Analytical Hierarchy Process method for Tarfresh Town. Middle East Journal of Scientific Research 2014; 22(9): 1294-1307.

[11] Alanbari AM, Ansari NA, Jasim HK, Knutsson S. Al-Mseiab Qadaa Landfill Site Selection Using GIS and Multicriteria Decision Analysis. Engineering 2014; 6: 526-549. http://dx.doi.org/10.4236/eng.2014.69055

[12] Yadav SK. GIS Based approach for site selection in waste management. International Journal of Environmental Engineering and Management 2013; (4): 507-514.

[13] Shahabi H, Keihanfard S, Ahmad BB, Amiri JT. Evaluating Boolean, AHP and WLC methods for the selection of waste landfill sites using GIS and satellite images. Environmental Earth Sciences 2013; 71: 4221-4233. http://dx.doi.org/10.1007/s12665-013-2816-y

[14] Mahini AS, Gholamalifard M. Siting MSW landfills with a weighted linear combination methodology in a GIS environment. International Journal of Environmental Science & Technology 2006; 10(3): 435-445. http://dx.doi.org/10.1007/BF03325953

[15] Oweis IS, Khera RP. Geotechnology of waste management. Boston: PWS 1998.

[16] Manoius V, *et al*. Using GIS techniques for assessing waste landfill placement suitablity. Case study: Prahova County, Romania. Geographia Technica 2013; 8: 47-56.

[17] Kontos TD, Komilis DP, Halvadakis CP. Siting MSW landfills with a spatial multiple criteria methodology. Waste Management 2005; 25(8): 818-83. http://dx.doi.org/10.1016/j.wasman.2005.04.002

[18] Yesilnacar MI, Suzen ML, Kaya BS. Municipal solid waste landfill site selection for the city of Şanliurfa- Turkey: An example using MCDA integrated with GIS. International Journal of Digital Earth 2.

Received on 10-08-2015 Accepted on 15-01-2016 Published on 12-02-2016

http://dx.doi.org/10.6000/1927-5129.2016.12.16