

Development of online Spatial Multi-Criteria Decision Analyst application: Case study on determining area suitability for school location in Surabaya, Indonesia

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Abstract. A decision sometimes needs to consider many aspects and to be judged by many people. Presenting a case of finding a suitable location for a new school this research proposes seven factors which its emphasis will be differently sorted by various people perspective. Each factor comes in a form of a multi-polygon layer that valued from 0 to 9, representing the suitability value of the certain aspect in the whole city area. The Public and some expert will judge by using the pair-wise comparison of those aspects. This research will provide web GIS application that will use by the public and the expert in this justification process and analyzing the result.

1. Introduction

Surabaya is an expanded old city and grows up reaching its form like today. Starting in the colonial era, Surabaya citizens lived in the district area. Surabaya populated area has expanded to the south, east, and west area. This expanded population is not accompanied by new public school development, especially the high school level. Figure 1 shows the distribution of school in secondary and high-level school respectively, overlaying the distribution of population areas. By a simple interpretation, it can be seen that the city has a lack of public high schools. It also shows that there exists a scarcity of educational institutions at the higher levels, making it common for students to travel much longer distances as they move to higher levels of study [6].

Surabaya city government need to build some new schools in an optimal location to increase the service and accessibility of education of the town. They have proposed some analysis factor that corresponded with school location. Those factors are Administration factor, Accessibility factor, Population factor, Public transportation factor, Land use factor, Student flow factor, and Public Preferences factor. Figure 2 shows these factors with a graduate colour presentation from green that indicates the most suitable location to red that indicates the least one.



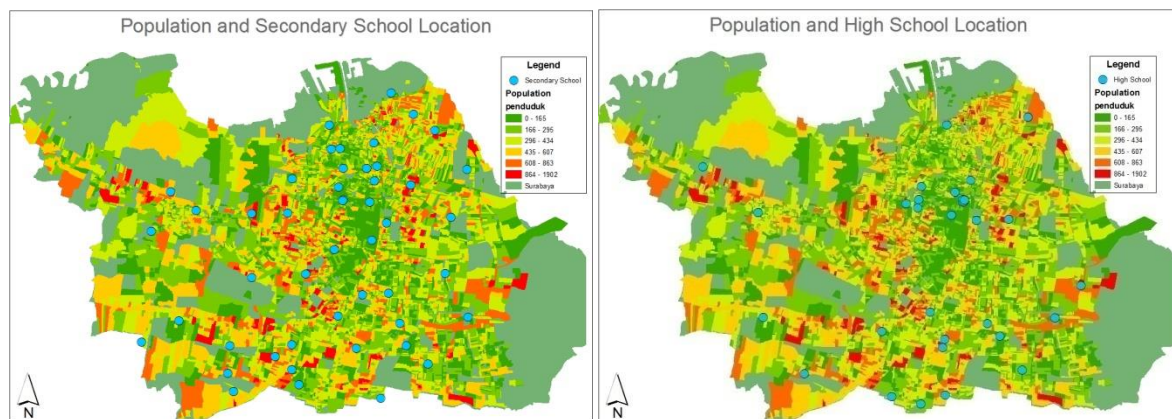


Figure 1. Secondary school map (left) and High school map (right) overlaying population layer.

Administration factor is a factor that represents the number of school in the sub-districts and its neighbourhood. The government want the schools spread over the sub-district equally. Thus, the sub-district that has no school and it surrounding sub-district also have no school will get high priority. Sub-district that already has school and it's surrounding has school will get low priority. This priority coloured from red to green to represent low to high priority.

Accessibility factor is a factor that calculated from school location and street network using Service Area analysis. An area that already has good accessibility to school is an area with low value because it does not need more school around. In contrast, an area with low accessibility will have high priority.

Population factor is a factor that calculated based on population number. High priority location is location with a high-density population.

Transportation factor is a factor that calculated by the number of public transportation in the area. An area with much public transportation routes founded will have high priority in placing new school.

Land use factor is a factor that based on the usability of the area. This factor wants to make the school area are close to vegetation and public facility area, and not in and in a distance from military, graveyard, and industrial zone. Thus, military, graveyard, and industrial zone, and also areas surround it was marked as low priority.

Student flow factor is a factor that calculated from the density of student passing through the area in their journey from their home to their school. An area that was passed though by the crowded student will have low priority for the new school location. A new school in a quiet area is expected to spread the crowd. Therefore, the quiet area marked as high priority.

Public preferences factor is a factor that excavates citizen preferences in choosing school location. A new school location will be better if it lies in the location that loved by the public. A survey for collecting public preferences has been conducted with a Web GIS application at <http://participatorygis.net>. This survey got public preferences by retrieving this information: a. Are they prefer the school located near their home, what is accepted distance, and how strong this preferences. b. Are they prefer the school located near their workplace, what is accepted distance, and how strong this preferences. c. Are they prefer the school located in some place along from their home to their workplace, and how strong this preferences.

This work wants to combine those seven factors with optimal weight setting. The optimal weight will be obtained from Multi-Criteria Decision Analyst method.

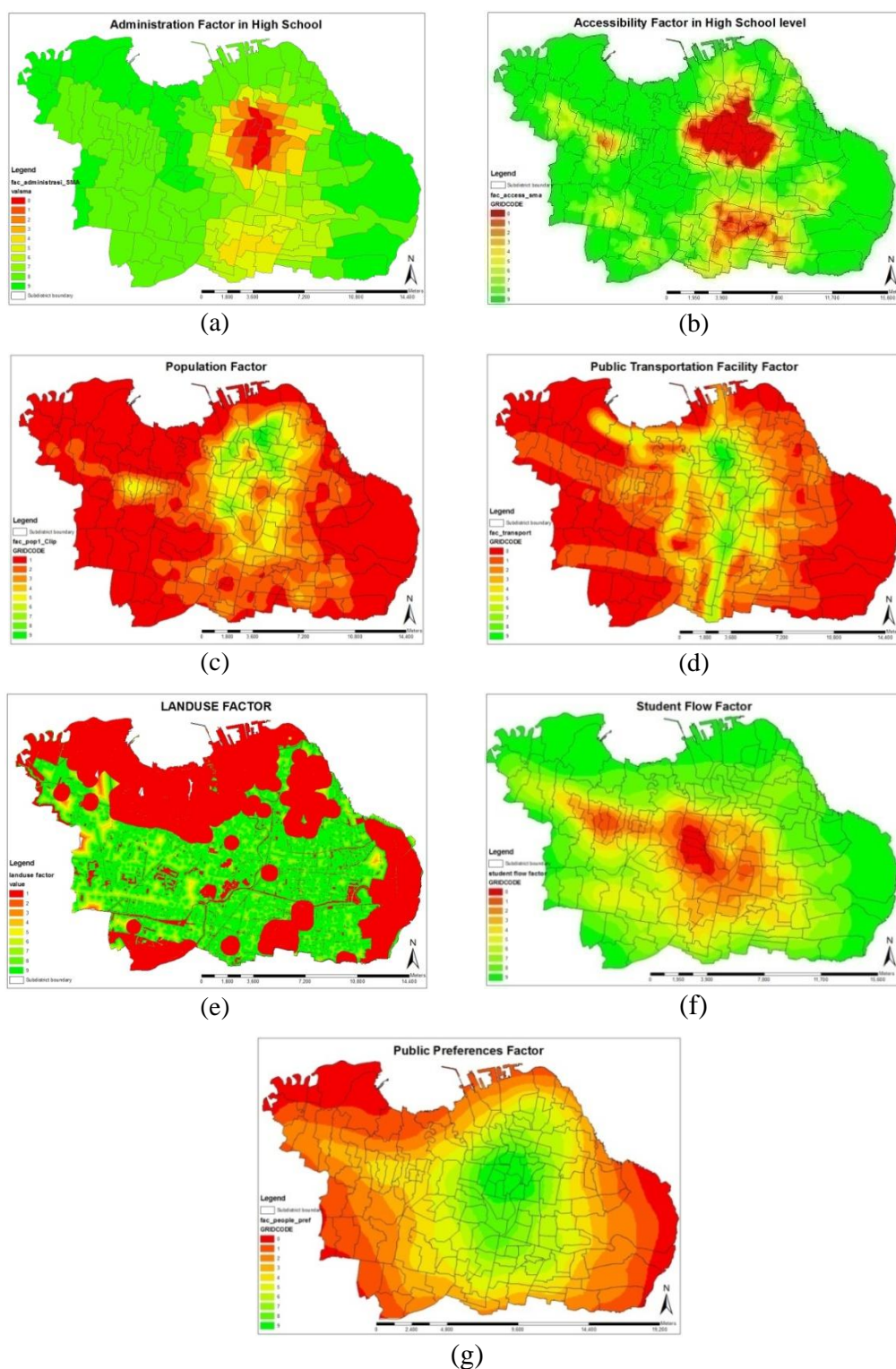


Figure 2.The seven factors. (a) Administration factor, (b) Accessibility factor, (c) Population factor, (d) Transportation factor, (e) Land Use factor, (f) Student flow factor, (g) Public Preferences factor.

2. GIS-MCDA

Since the 1990s, the combination of MCDA and GIS has been promoted for use in solving spatial problems in urban planning, forest conservation and site determination [1]. In land-use suitability assessment, for example, alternative options and preferences for land use can be determined using MCDA, through the identification of desirable objectives, related attributes, and criteria, such as social, economic, environmental and ecological factors. Some successful work of combining GIS and MCDA can be seen in the work of Jessy Paquette and John Lowry about assessing flood hazard [7], BachtiarFezizadeh and Thomas Blaschke about landslide analyzing [8], Gbanie and colleagues about modelling landfill location [9], and Hamadouche and colleagues about finding best preservation area [10].

Quantitative analysis is necessary for MCDA, including scoring, ranking and weighting. A single conclusion is produced after the quantitative analysis. Phua and Minowa work explain that the main steps in MCDA for land-use suitability assessments include defining the objectives and the corresponding judgment criteria, analyzing the criteria, assessing the standards, quantitatively analyzing the criteria for the assessment units and aggregating the judgments. GIS-MCDA is a process that transforms and combines geographical data and value judgments (the decision-maker's preferences) to obtain information for the decision making. Different GIS-MCDA techniques exist depending on the operations needed to obtain the final valuation of the solution alternatives [2]. Vega and colleagues mention that in some cases, these transformations may be simple arithmetic operations as in the weighted linear summation methods, but in others, as for example for the ideal/reference point or the outranking methods, more complex operations is needed.

Great work of Chakhar and Martel make classification of GIS and MCDA integration. There are three types of GIS and MCDA integration. Those are Indirect, Build In, and Full integration [3]. In an indirect GIS-MCDA integration mode, integration of GIS software and stand-alone MCDA software is made possible by the use of an intermediate system. The Intermediate system permits to reformulate and restructure the data obtained from the overlay analysis which is performed through the GIS into a form that is convenient to the MCDA software. The other parameters required for the analysis are introduced directly via the MCDA software interface. The results of the analysis (made in the MCDA part) may be visualized by using the presentation capabilities of the MCDA package, or feedback to the GIS part, via the intermediate system, for display and for further manipulation. A built-in GIS-MCDA integration mode In this mode, a particular MCDA model is directly added to the GIS software. The MCDA model develops its own database independently but still integrated. The use of the interface of the GIS part alone increases the interactivity of the system. Here, there is no need for an intermediate system because the MCDA model is reformulated in such a way that the exchange of data and analysis results between the two parts is performed directly. Full GIS-MCDA integration mode, the third mode, yields itself to a fully GIS-MCDA integrated system that has a unique interface and a unique database. Here, the MCDA model is stimulated directly from the GIS with standard spatial operation tools. The GIS database supports both the geographical and descriptive data and support the parameters required for the multi-criteria evaluation techniques. The single theme of graphical interface makes the system fully integrated.

There is some method experimented to get a better decision. However, AHP is the popular one. AHP is becoming one of the most common methods of coupling decision-making processes and geospatial analysis [4]. AHP is the simplest decision-making method to be prototyped. It means the formula is easy to implement. However, it provides accurate results in geospatial analysis. AHP has become popular due to its straightforward implementation and positive results. These characteristics served as the basis for this research to develop a simple but functional geospatial AHP-based decision-making framework which serves as a mechanism that ranks inputs and produces output maps input ranking–output maps mechanism facilitating decision making at different levels. AHP method, cited from work by Karnatak and colleagues [5] about finding best site for biodiversity conservation, in any decision making process the decision maker has to identify the goal or ultimate objective of decision problem.

In AHP the decision maker initiates to identify the objective and decision problem. The process continues to the choice phase. The main objective of this phase is to select one particular alternative from a set of known options. Therefore, the first step is to list all the alternatives. It continues to define the criteria that will be used to judge the alternatives and develop a decision hierarchy. The hierarchy represents the structure of the decision problem and forms the basis of the comparisons. The next step in the AHP process is pair-wise comparison alternatives, i.e., for each criterion; the decision maker compares all the alternatives pair-wise. The decision maker can make numerical or verbal judgments. In the verbal mode, statements are selected varying from 'equally prefer' to 'greatly prefer'. In the numerical method, the decision maker selects a score on a scale of one to nine.

3. Methodology

There is some option for implementing Web GIS application. Some of them are by spatial services server like Mapserver or Geoserver. Both can directly connect with map files and send data to the client request and show the map in client's web browser. But they need a particular handle in the server. We must own the server by ourselves or we have to pay more hosting service that includes Mapserver or Geoserver, a service that not exist in the common hosting provider. Another way that can be hosted in common hosting service is to store the map in a common database like MySQL or Postgres and using Javascript based tool for showing the map in client's browser. This work is using this second way. Factors Layers in previous section comes in a form of a shapefile with detail resolution. In average it has size about 600 Kbytes per factor. It is big enough for taking time in the process of showing the map in the browser. In the MCDA process, the map will be simplified to 20% of the real size to supply fast respond to the user. Thus, what will show in the MCDA web application is not the actual map, but still have a good representation of the real condition. By referencing classification of Chakhar and Martel, this work becomes Indirect GIS-MCDA since the MCDA process does not connect with the original spatial data, but it come with a facility to show the simplifying map for better user understanding.

There are three big steps in this work: Data Preparation, Judgement process, and Result Calculation. Figure 3 showsthesesteps.

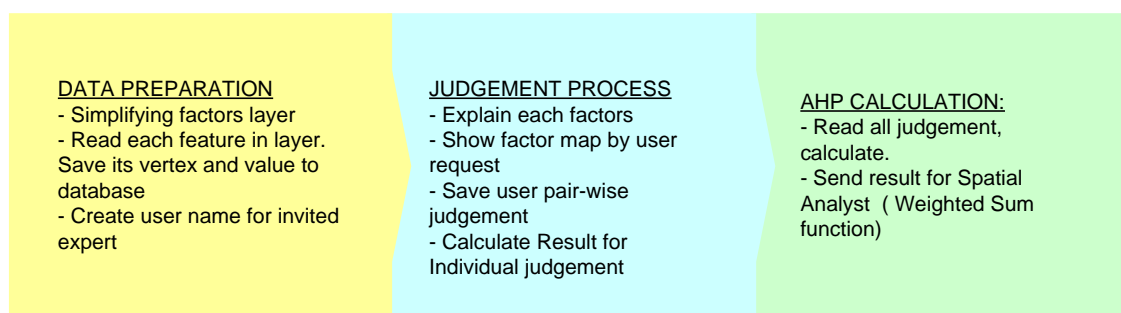


Figure 3.Processes in the GIS-MCDA.

3.1 Data preparation

This step use three tools: ArcGIS 9.3, Visual Basic 6.0 and MySQL. ArGISis used to simplifying the polygon factors. It uses 'simplify polygon' function from Generalization tool package. The simplified polygon then read by a custom application made from Visual Basic 6.0 equipped with ShapefileReader library. It read polygon by polygon in each shapefile and put the vertex data to MySQL database. The Database structure is shown in Figure 4.

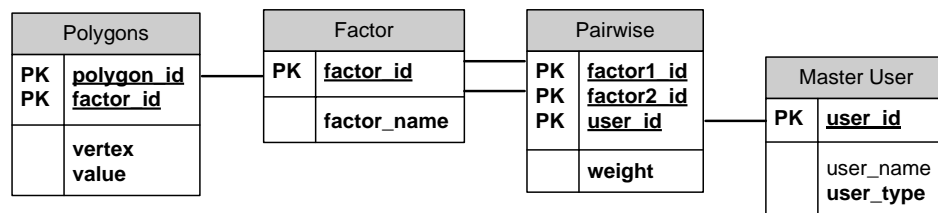


Figure 4.Database Structure.

The database has four tables. Those are table Factor, table Polygons, table Master_user, and table Pairwise. Table Factor stores list of factor layer. Table Polygons store a collection of the polygon that constructs factor layer. Table Master User saves user data that will give judgment in MCDA process. Table pairwise is saving the pairwise judging from the user. There are two types of user, Public and Expert. The public user data will generate automatically when they start using the MCDA application. In contrast, user data for the expert user need to be prepared. The User Id and User Name field have to be filled first; then User ID will be informed to the expert before they are using the application. They have to use this ID in the login page. At this step, data preparation process is done.

3.2 Judgement process

The judgement process uses web-based application. The application builds using PHP language, above MySQL database, and OpenLayers library for presenting the map. The application has three pages. The first page is a login page. In this page, the user has to choose whether they are will login as Public or as Expert. If the user selects an expert door, they must type their gifted ID. The second page is an introduction page. It explains all factors that will be judged. The user also can see a presentation of each Factor on the map, as an overlay layer in the Google map. Figure 5 shows this second page.

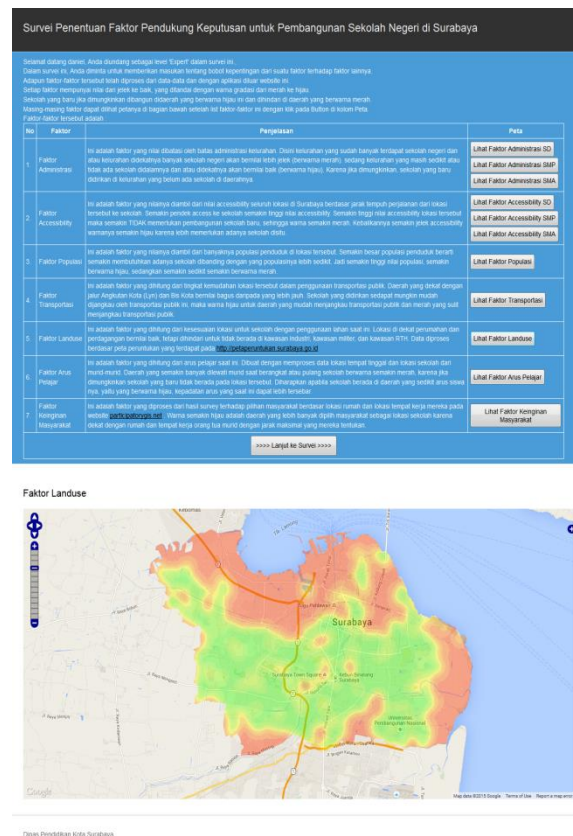


Figure 5.Introduction page.

The third page is the pairwise judgement page. The user has to decide each factor whether it have influence in choosing the location as absolute strong, very strong, strong, slightly strong, or the same strong with another factor. There are 21 pairs of seven factors. It means user have to make judgement 21 times with different factor pair. After the user makes decision for all pair combination, the user can take a look the result for their judgement. The user input will be calculated in AHP method. This step is the first calculation in this work. The second calculation will be used in the combining process of all respondent's judgement. The calculation method will explain in the next section. This calculation will generate the weight for each factor. These weights will be used to define the transparency of factor layers while it is drawn in the browser. Each layer, using the polygons value, will display with graduate colour from red to yellow to green colour. All factor layers will overlay with different transparency value. This step will make a city area that coloured by seven different layers. Green area indicates that area have dominant green coloured polygons from all layers while red area has dominant green coloured polygons. Figure 6 shows this third page.

Figure 6. Pairwise judgement page.

3.3 AHP calculation

AHP Calculation step will do after all respondents done the pairwise judgement. Not all result will be brought to the final calculation. Only the credible result that passed the consistency ratio will be used in the next stage. All valid respondent result then will be combined with geometric mean formula. This process uses visual basic 6.0 application for read from MySQL database and calculates the result and display the calculation and result in Microsoft Excel. Below is the algorithm for this process, explained along with Figure 7 that show the example of a respondent calculation and Figure 8 that shows the equation of consistency ratio.

- *Looping for all respondent judgement*
 - *For every judgment, make a comparison matrix (see Figure 7 range A1:H8)*
 - *Sum each column. (see Figure 7 range A10:H10)*

- Make second matrix by Normalizing relative weight by divide each cell in the first matrix with the sum of column (see Figure 7 range A12:H19)
- Calculate Average of every value in a row in the second matrix (see Figure 7 range J13:J19). This will become weight result if Consistency Ratio (CR) is accepted.
- Multiply above average with the corresponded Sum (see Figure 7 range H13:H19), Sum the result to get λ_{max} (see Figure 7 cell H20)
- Calculate Consistency Index CI using λ_{max} , then calculate Consistency Ratio (CR) using CI and Random Consistency Index (RI), which for $n=7$, $RI=1.32$. If $CR < 0.2$ the result is accepted and use for calculate all weighted mean.
- Combine all accepted respondent result by using Geometric Mean formula.

Geometric Mean formula will produce the final weight of each layer. Next, the last step, is bringing the final weight of each factor in the ArcGIS 9.3. The real factor layers, not the simplified ones, will use this weight in the ArcGIS Weighted Sum function.

	A	B	C	D	E	F	G	H	I	J	K
1		adm	acc	popul	trans	landuse	flow	pref			
2	adm	1	0.2	0.33	5	3	5	7			
3	acc	5	1	1	3	5	5	7			
4	popul	3	1	1	7	7	7	9			
5	trans	0.2	0.33	0.143	1	1	3	5			
6	landuse	0.33	0.2	0.143	1	1	0.33	3			
7	flow	0.2	0.2	0.143	0.33	3	1	3			
8	pref	0.143	0.143	0.111	0.2	0.33	0.33	1			
9											
10	SUM	9.873	3.073	2.87	17.53	20.33	21.66	35			
11											
12		adm	acc	popul	trans	landuse	flow	pref		W	W*SUM
13	adm	0.101286	0.065083	0.114983	0.285225	0.147565	0.23084	0.2		0.163569	1.614916
14	acc	0.506432	0.325415	0.348432	0.171135	0.245942	0.23084	0.2		0.289742	0.890378
15	popul	0.303859	0.325415	0.348432	0.399315	0.344319	0.323176	0.257143		0.328808	0.94368
16	trans	0.020257	0.107387	0.049826	0.057045	0.049188	0.138504	0.142857		0.080724	1.415084
17	landuse	0.033424	0.065083	0.049826	0.057045	0.049188	0.015235	0.085714		0.050788	1.032521
18	flow	0.020257	0.065083	0.049826	0.018825	0.147565	0.046168	0.085714		0.06192	1.341182
19	pref	0.014484	0.046534	0.038676	0.011409	0.016232	0.015235	0.028571		0.024449	0.855712
20										$\lambda_{Max}=$	8.093473
21										CI=	0.182246
22									RI(7)=1.32	CR=	0.138065

Figure 7. Example of the single calculation.

$$CR = \frac{CI}{RI} \quad CI = \frac{\lambda_{max} - n}{n - 1}$$

Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Figure 8. Formula for calculate Consistency Ratio (CR).

4. Result and discussion

The web-based application build in this work is still active and still collect Public opinion at <http://ristek.net> until now. The Experts comes from the government, scientist, and professional. This research subject is having immediate concern within two departments in Surabaya city, the Educational Department and Planning and Development Department. According to that, the first type of expert respondents consist of the head of those two departments, and it's subordinate that concern with this subject. Some Scientist from Surabaya Tenth November Institute of Technology from Urban Development Department also invited to join as MCDA respondent. Some professional who support Surabaya city government and have a concern in Urban Planning work are also encouraged. They fill in by themselves in the online application independently. The expert respondent result shows that they prefer school location mainly have to be placed in the area with having high population. The next factor with high priority after population factor is the administrative factor, accessibility factor, and transportation factor. Figure 9 shows the final weight of expert judgement result and the final reliability area map.

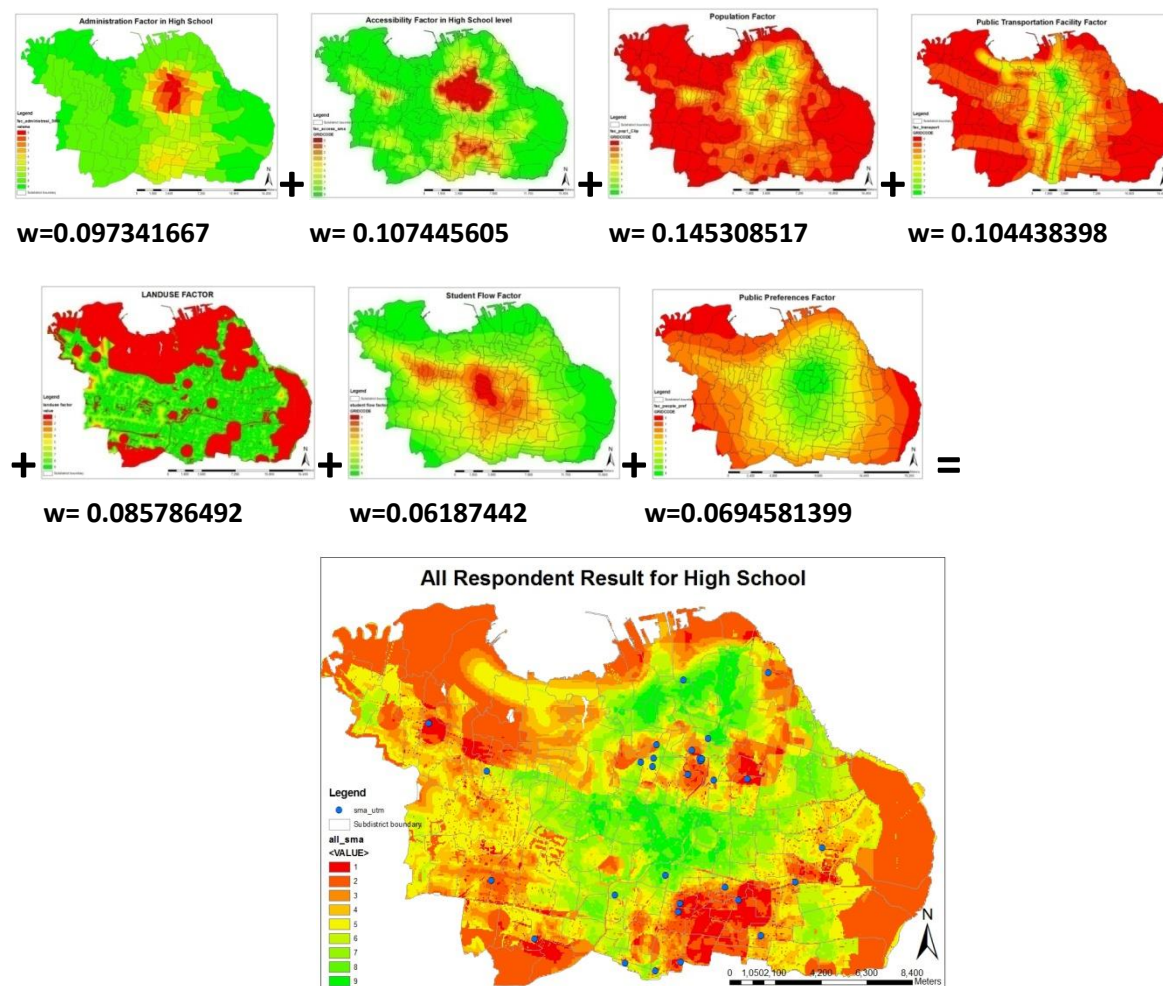


Figure 9.Final result calculated from 'Expert' respondent.

From the final weight discovered by AHP calculation, it can be seen that Expert are choosing population factor as the main factor. The weight have significant gap from the second position. In the next position there is the second group of factors with slight different value; those are transportation factor, accessibility factor, and administration factor. The rest are factors that not considered as primary factors, those are land use factor, student flow factor, and public preferences factor.

5. Conclusion

This outcome then informs back to the Expert respondent to get their opinion about the research. All respondent can accept the result and appreciate the application. The web-based Application as a product of this research has been proven can be used to find a suitable location for a new school by using multi-criteria decision analyst. Some other research that has to be decided by multiple factors and by many respondents which have to work remotely can duplicate the model proposed in this research for their tool.

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