

Spatial zonation system with Voronoi diagram and Delaunay triangulation to improve management education

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Article Info

Article history:

Received May 15, 2022

Revised Jul 10, 2022

Accepted Sep 23, 2022

Keywords:

Management education

School zonation

Triangulation

Voronoi diagram

Web-GIS

ABSTRACT

The zonation system is one of the efforts of the Indonesian Government to improve the quality of education services continuously, but the implementation is still considered less useful. Some areas were still grouped into the different zone from the original. Based on this problem, the solution needed for the zonation mapping of each school so that the apparent zonation limit can be resolved. An application that can map schools in an area based on housing for prospective students is a solution that can be considered at this time. This research showed the implementation of Voronoi diagrams to cluster the area based on the school position within Bengkulu City. The system was also capable of mapping the residential of the student address to match the choice for registration in available secondary school and senior high school. The implementation of the system showed a better result for school zonation over Bengkulu City based on web geographic information system (Web GIS). Furthermore, the comparison analysis over the existing system also showed that the performance of the Voronoi diagram for school zonation the method could solve the problem of the overlapping zonation with Radius method. Three hundred fifty students validated this system to show the performance of this method. The result showed that 72.05% of students matched the first choice, while 27.95% of students matched the second choice. This research showed the analysis of the value of this gap appeared due to the student preferences and school capacity factors.

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1. INTRODUCTION

Schools are a primary tool to fulfill the community's needs for education in Indonesia, as the article 31 paragraph (1) of the Constitution 1945 [1], [2] states that every citizen is entitled to an education. The implementation of this education process is applied to educate and to develop the moral of the nation to be better and be dignified. Education is one of the essential things that encourage the government to improve the quality of education services continuously [3], [4]. The improvement of the national education system by the government conducted for general and thorough quality improvement, especially for schools in order to have quality equality, i.e. zonation system [5], [6]. The provisions of this zonation system are mentioned in local government regulations, to be regional scheme. Regulation of the Governor of Bengkulu number 24 the year 2018 which reads [7]: The selection of prospective new students of grade 10 of high school considers criteria

with the order of priority under the capacity of the following group of studies i) The distance of residence to school under zonation provisions; ii) National exam result letter of secondary school (SMP/Madrasah Tsanawiyah) or other forms of equal; iii) Achievements in academic and non-academic areas recognized by the school. Another regulation is Regulation of the Mayor of Bengkulu number 24 [8] the year 2017 which reads: Selection of prospective new students of grade seven of SMP or other forms that are equal to consider criteria with the order of priority under the capacity of the group to learn as i) distance of residence to school under zonation provisions at the highest 15 years old; ii) The value of elementary school (SD) exam results or other forms of equal; iii) Achievement in an academic and non-academic school recognized. The list of school used by this research were describe in Table 1.

Table 1. School in Bengkulu

| District | Secondary | High school |
|------------------|-----------|-------------|
| Ratu Agung | 2 | 1 |
| Gading Cempaka | 3 | 1 |
| Selebar | 4 | 2 |
| Teluk Segara | 3 | 1 |
| Sungai Serut | 2 | 1 |
| Muara Bangkahulu | 3 | 2 |
| Ratu Samban | 2 | 2 |
| Singaran Pati | 3 | 1 |
| Kampung Melayu | 3 | 1 |
| Total | 25 | 11 |

Source: [9]

School zonation has been a central problem to distribute the student within the residential area. Furthermore, the distribution could also lead to further policy implementation to improve the school and education management over Bengkulu City. However, in the implementation of the zonation system over Bengkulu City is still considered as questionable decision due to inequality over the quality standard. Referring to the decision of Regulation of the Minister of Education and Culture (Permendikbud) No. 14 of 2018 [10], [11] which is the determination of the zonation radius of the zonation system itself is determined by the local government by involving deliberation or working group of the school principal. In this case considered the provisions of the zonation is less satisfactory because there are still many problems including i) Dissemination of uneven public schools in each district and village; ii) Some prospective students cannot be accommodated because they can not apply to any school. While there are some schools still have lacks students because it is far from population settlements; iii) Distance determination or scope of zonation with the determination of zonation point from Neighborhoods. The Distance, the unalignment of the location and the shortage of public schools, is polemically faced by the zonation system. This condition raises many areas that are not assembled in the zonation so that many students who do not fit in public schools and at the upper-middle level prefer admission to vocational high schools that use the written exam system to enrol schools [4], [12]. The current depiction of school zonation in Bengkulu describes in Figure 1.

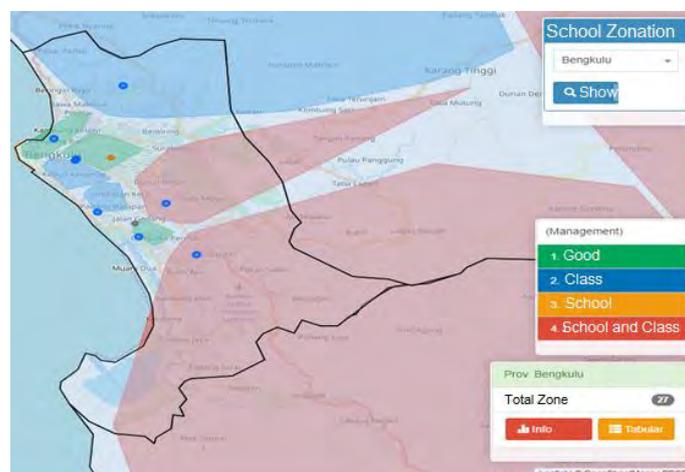


Figure 1. Current zonation system in Bengkulu

From Figure 1 (can be accessed via <https://map.siap-ppdb.com/>), we can see that current zonation still have some of the areas beyond the coverage of allotment. The issues about zonation for new student admissions in Indonesia is the right and courageous policy, but has been executed very poorly [13]. The government proposed to make the mapping of school zonation through the Voronoi diagram as practised either in whole or in part in several cities in Australia to see zonations that cover a public school. The government can also learn from the application of the school zonation system, which is implemented in New Zealand, England, France, Sweden, Finland, Estonia, and Japan. Here we show the new approach of how to get school zonation in Indonesia, especially Bengkulu to see the better coverage of optimum school zonation for a better distribution.

2. RESEARCH METHOD

Explaining research chronological, including research design, research procedure (in the form of algorithms, Pseudocode or other), how to test and data acquisition [14]–[16]. The description of the course of research should be supported references, so the explanation can be accepted scientifically [17], [18]. This can be presented as in the development of waterfall method. The waterfall model provides a sequential or sequential flow of software approach starting from analysis, design, coding, testing, and support phase [19], [20].

2.1. Bowyer-Watson algorithm

One algorithm used to form a triangulation diagram is the bowyer-Watson algorithm. The Bowyer-Watson algorithm is an incremental algorithm. The Bowyer-Watson algorithm works by adding points one at a time to a valid Delaunay triangulation of a subset of the desired points [21]–[23]. After each insertion, each triangle whose circle contains a new point will be deleted, leaving a hole a star-shaped the polygonal hole that then triangulates using a new point. By using triangulation connectivity to efficiently find the triangle to be removed, the algorithm can take an $O(N \log N)$ operation to triangulate the N -point, although there are special degeneration cases where it rises to $O(N^2)$ [24], [25]. The Bowyer and Watson algorithms are known as delete algorithms or delete and build or build because they add dots Sequentially Into existing Delaunay triangulation. The Bowyer Watson algorithm is simulated at five points in R2. Each step after (a), the new Delaunay edge is shown in blue. Note that at each step, we add at most two triangles to triangulation, which is a common result in two dimensions. Remove all the triangles that share the point with the Super triangle leaving Delaunay triangulation of five points in step (f).

2.2. Delaunay triangulation

In mathematics and computational geometry, Delaunay triangulation (DT) or DeLone triangulation is a set of points in the P field is a no- triangulated DT (p), so no point of the p contained in the cycle of rotating any triangle in DT (p). Delaunay triangulation maximizes the minimum angle of all triangular angles that exist in triangulation. Delaunay is also an algorithm focused on segmenting and merging, as well as a point insertion method per point of the triangulation algorithm [21], [26]. This triangulation was discovered by Boris Delaunay in 1934. The Bowyer-Watson algorithm is relatively more efficient when $O(n \log(n))$, by repeatedly adding one vertex at a time and re- triangulating the affected parts on the chart. In the divide-and-conquer algorithm, the lines are recursively drawn to divide the knot into two groups, and the Delaunay triangulation is then implemented [25]. Delaunay triangulation according to [29] refers to a set of dots on an area of the field, where there is no point in the circumcircle of any triangle that exists in the triangulation. In Delaunay triangulation, no circle contains a triangle in the inside. This ensures Delaunay triangulation maximizes the minimum angle among all possible triangulation of the set point. The process starts from building Delaunay triangulation with the P set points as a starting point, the initial repository must be created. From a geometric point of view, the repository is the first triangle in Delaunay triangulation and big enough to load a whole set of point P . The vertices of the Super triangle are: three additional points, P_0 , P_{-1} and P_{-2} .

Voronoi diagram as shown in Figure 2(a) is one of the first branches of the geometry of computation science that first appeared in the 17th century by Rene Descartes and developed by Dirichlet in 1850. The case handled using the most spectacular Voronoi Diagram was the case of cholera disease in England in the year 1854 by physicist John Snow [27], [28] where he described how some people died of living cholera disease in a place closer to the water pumps infected from other pumps. Later in 1907 a Russian mathematician, Georgy F. Voronoi expanded to a higher dimension and was formally published in the year 1908 [20], [29]. The Voronoi diagram is a division of the area of the field into parts based on the distance from the dots on a specific subset of the area of the field called the process of triangulation as in Figure 2(b). The set of these points is determined first, and for each point has a region each where each coordinate of the region is closer to that point than the other points. These areas are called the cells of Voronoi [23], [30]. Triangles that have the same side would be grouped and then the center point of the circumcircle of the two

triangles will be associated with the line. After all the triangles that have the same sides as the other triangles are connected, the Voronoi diagram will be formed and implemented into the system as in Figure 3.

The system workflow analysis is important to do because the analysis aims to explain the workflow of the system in order [31], [32]. System analysis is part of the research that analyzes the existing system, where its function is to design a new system or update an existing system. This is the most important part that will be built depending on the analysis. The next is a working flow of the zonation system with the method Voronoi diagram as in Figure 4. It is starting from the system will display a map of Bengkulu City with Voronoi, which then ask the input manually by the user i.e., the input point of the address. After that, the zonation is then taken up by the Voronoi diagram which generates the zonation result and if it fails it will return to the address input process. The result of zonation will be followed by the recommendation of the school. If you want to do the repetition, then go back to the address input process. In the decision section of zonation with the method of Voronoi diagram is the most important part to be built depending on the analysis done. There are some important terms that have been marked by using thick text in the flow of the zonation system: i) Triangulation: A set of nodes that form a triangle with the provisions of no more nodes inside the set of nodes; ii) Super-triangle: A large triangle where all the input points are in the triangle; iii) Circumcircle : a circle on the outer part of the polygon (triangle), which touches three triangular vertices and the center is known as the circum centre; iv) Poinlist: A set of coordinates that determines the point to be triangulated. The method used should be accompanied by references; the relevant modification should be explained. The procedure and data analysis technique should be emphasized in a literature review article. The stages and analysis of the research must be explained in detail.

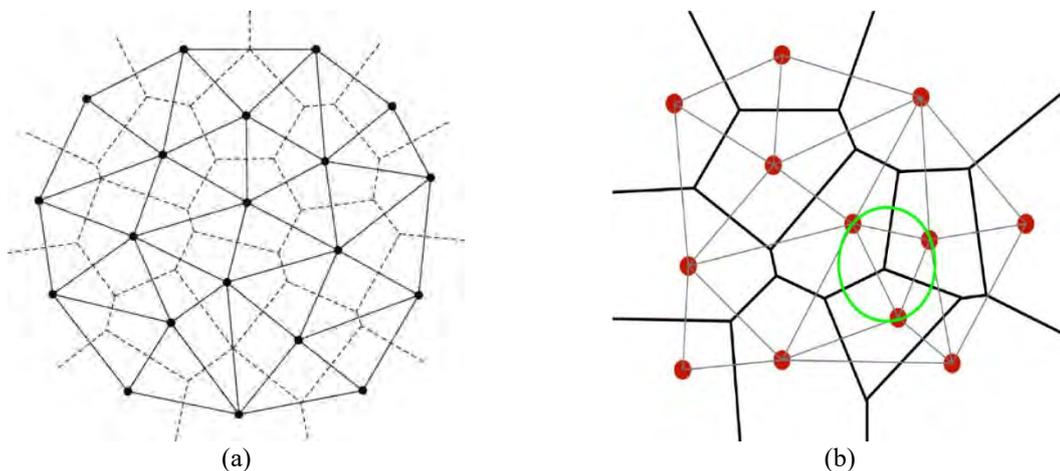


Figure 1. The development process of Voronoi from the process of (a) Delaunay diagram (b) triangulation process based on the location (Colombia, 2016)

3. RESULTS AND DISCUSSION

3.1. System implementation

This process of algorithm was implemented into the web system to see the performance of Voronoi diagram for zonation in Bengkulu. Main page of the Bengkulu City school zonation system is the first interface seen in the system. The main page is contained of general information about school in Bengkulu that consist of available school can be chose by the student based on the area they lived. It is powered with the location setting based on the device used by the student to see real time location to be able to locate three main schools nearby based on the diagram of Voronoi.

Seen at the beginning of the display if not selecting a school level, then it will only be seen a map of Bengkulu City empty. However, on the left side there remains a search menu, and a school level. This appearance also includes the process of location search to see where the location belongs in the zonation system Figure 3 shows how the location search in the system. After entering the address of the prospective student, the results will come out through a search based on the Voronoi zonation that has been created. Seen in the picture the user inputs the address, for example Pematang Gubernur, Bengkulu City. The results showed that the zonation for the students was High School 8 Bengkulu City for the first zonation with 0.16 km, for the second zonation, namely High School 9 with 3.19 km and finally High School 6 Bengkulu City with 4.83 km.

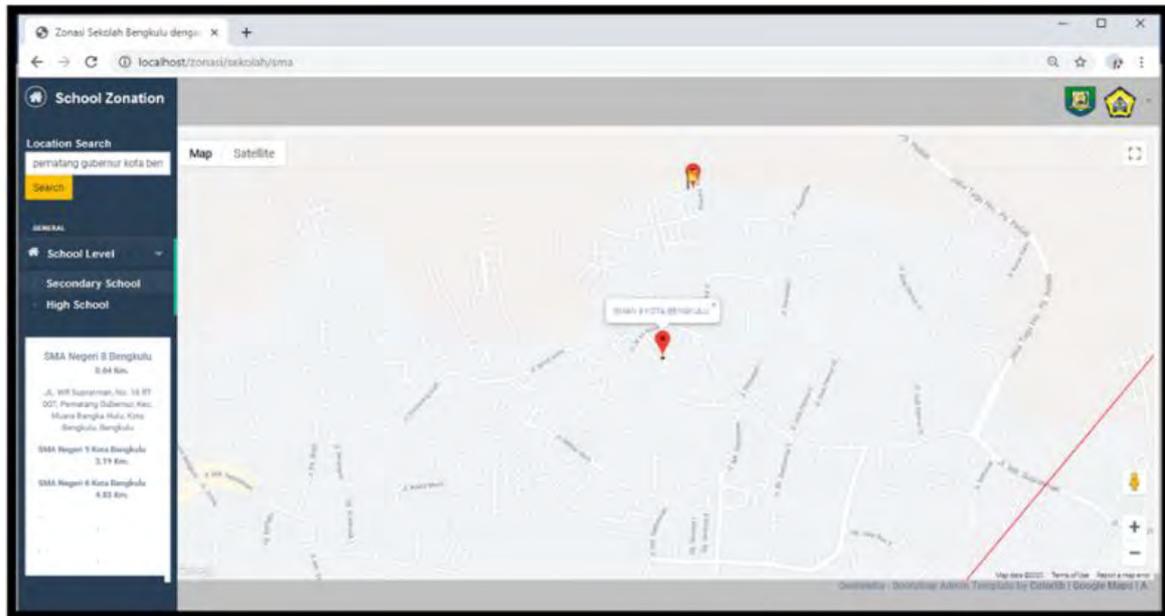


Figure 2. Location search on system

3.2. Zonation

The process begins with an empty triangulation, in which the data structures of the triangles are not yet interconnected. All points that are inputted will form a Super-Triangle in which there are all points in the pointList, then check in process three whether there are points in the Super-Triangle where the line drawing has not been processed. It is because in a Super-Triangle a line is drawn between the points and the corners of the Super-Triangle [33], [34]. If there are no more or everything has been processed, the triangulation will end. However, if there are still points that have not drawn a line, then proceed to empty bad triangles, which mean that the process will be checked whether there is still a line between the points and the Super-Triangle corner. If not, it will enter the final process, which is the ninth, which is included in the empty polygon list, if it is true, it will enter stage six where the step is to check first whether there are still points in the circum circle of a triangle, if not then all points have been processed, but if then the point will be listed in the bad-triangles triangle. if not, then the triangle process is over and back to check to selection six [35], [36]. Furthermore, the last process, if it is in correct condition, will be included in the empty polygon list, while if it is wrong, it will return to process five. The results of bad triangles will be continued on the next flow chart to generate triangulation and will complete the process in Delaunay triangulation. When the Delaunay process ends, it will be continued with the stage of producing a voronoi diagram as shown in Figure 4(a) for secondary school (SMP) and Figure 4(b) for senior high school (SMA).

If when checking there is no triangle in the bad-triangle list, it will delete it from the triangulation because there are still points inside the circum circle and continue to ask whether all triangles in the bad-triangle have been processed. If the list contains triangles, it will be checked whether there are still starting points in the polygon list. If true, then a new triangle definition will be from the vertex of the polygon list drawn to the super-triangle. The process followed by adding a new triangle from the edge to the triangulation result. All processes will end in the selection condition whether all triangles have been processed and have all the points been processed. When it is finished, triangulation will be generated but if not, then the process will return to the beginning. For the Delaunay Triangulation stage, it is finished at this stage, which will then enter the flow chart to create a voronoi diagram that comes from the previous Delaunay triangulation. If in the third process produces the correct condition, then it will be done to produce a new Edge process (triangle circumm center edge to edge) and proceed to add a new edge to the edge list and all processes are completed.



Figure 3. Delaunay triangulation for (a) secondary school and (b) senior high school

3.3. Developing the diagram for each school

When the user has chosen the school level to the High school option, it will look a red line that is the zonation of Voronoi itself, on the left side seen in the image will appear points of school and Red Line which is The Voronoi line which means the school zonation, describe in Figure 5 (senior high school zonation) and Figure 6 (secondary school zonation). When the user has selected the school level to the Senior high school, then input the address of the prospective student, the page will move to the School Zonation result and to have the address point of the house, describe in Figure 5. After inputting the address of the prospective student, the system will exit the results by searching the created Voronoi zonation. The result of the zonation prospective students is the 8 state Senior High School Bengkulu City for the first zonation with 0.16 km, for the second zonation namely the Senior High School num 9 with the distance of 3.19 km and the last 6 senior high School in Bengkulu with 4.83 km. When the user has chosen the school level to the secondary school, it will look like the following image: The admin home page is the first page accessed when the admin has entered the username and password correctly. On the main page there is also a button to log out if you want to quit the system where it is located on the username. If you want to re-enter the stay pressing the following button is the home page view.

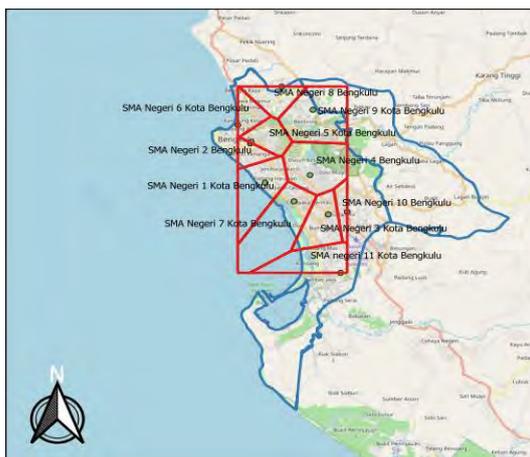


Figure 4. High school zonation development

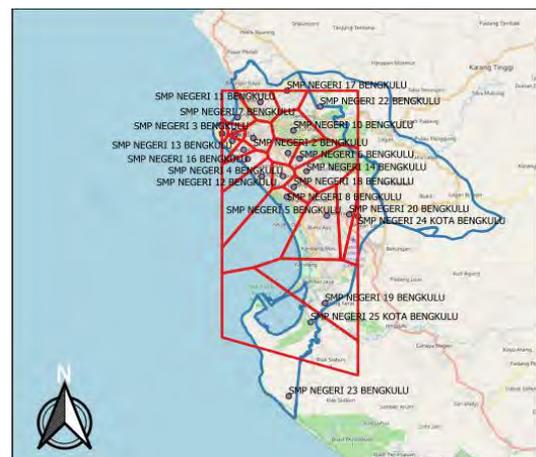


Figure 5. Secondary school zonation development

The digitation of the system can be done by using the input data interface in the system interface. To check how the results of the Delaunay triangulation and how the shape of the results of the coordinates of the junior and senior high school in Bengkulu City was made a mathematical model of the QuantumGIS or qgis application. Figure 5 and Figure 6 are the result of the Delaunay-triangulation when illustrated by the application of a quantum geographical information system.

3.4. System validation

Figure 3 is the core of the interface implementation of the built-in system. In this system, there is a page for common users that are public pages while the home page, the admin data page can only be accessed for admins of that system build with the integration of web and GIS [37]–[39]. The result of the system had been tested using the black box testing method to calculate the functionality rate over the process in the system background [40]. The result and the process of the testing is shown in Table 2.

This research also tested the usability of the system by comparing the result based on the existence system owned by the ministry. The result of this Voronoi-based zonation system is then compared to the zonation result of the Bengkulu city government school year 2018/2019 with total 350 students. This research found that in total total of 87 students not compliant zonation with 27.95% of students not corresponding zonation provided by the government. Total 263 Students according to zonation with 72.05% of students per zonation. From the result of the graph produced by the Voronoi Diagram, this research has successfully covered the gap of the address that is not covered by the radius system right now. This approach also showed a good performance to see the details address of the proposed pupils that will register into a new school based on zonation area. This system was also capable to measure the distance of the address with the Voronoi length and the nearest main road over the point.

Table 2. Functionality test

| Activity | Realisation | Result |
|--------------------------------------|-----------------------------------|-----------------------------------|
| Main page | | |
| Main page menu OnClick | Show main page | [V] Succeeded [] Unsuccessful |
| Menu page senior high school OnClick | Show menu page senior high school | [V] Succeeded [] Unsuccessful |
| Menu page secondary school OnClick | Show menu page secondary school | [V] Succeeded [] Unsuccessful |
| Senior high school page | | |
| Main page menu OnClick | Show main page | [V] Succeeded [] Unsuccessful |
| Input address search OnClick | Show input address search | [V] Succeeded [] Unsuccessful |
| Search button OnClick | Show search result | [V] Succeeded [] Unsuccessful |
| Secondary school page | | |
| Main page menu OnClick | Show main page | [V] Succeeded [] Unsuccessful |
| Input address search OnClick | Show input address search | [V] Succeeded [] Unsuccessful |
| Search button OnClick | Show search result | [V] Succeeded [] Unsuccessful |
| Admin login page | | |
| Input wrong user or password | Dialog box to warn the wrong data | [V] Succeeded [] Unsuccessful |
| Input right user or password | Show the main page | [V] Succeeded [] Unsuccessful |
| Admin main page | | |
| Main page menu OnClick | Show main page | [V] Succeeded [] Unsuccessful |
| Senior high school page OnClick | Show senior high school page | [V] Succeeded [] Unsuccessful |
| “Edit” button OnClick | Show editing page | [V] Succeeded [] Unsuccessful |
| ‘Submit’ button OnClick | Save changes on data | [V] Succeeded [] Unsuccessful |
| ‘Reset’ button OnClick | Reset the data | [V] Succeeded [] Unsuccessful |
| Senior high school page OnClick | Show senior high school page | [V] Succeeded [] Unsuccessful |
| “Edit” button OnClick | Show editing page | [V] Succeeded [] Unsuccessful |
| ‘Submit’ button OnClick | Save changes on data | [V] Succeeded [] Unsuccessful |
| ‘Reset’ button OnClick | Reset the data | [V] Succeeded [] Unsuccessful |
| Succeeded scenario | 20 | |
| Total scenario | 20 | |
| Functionality | 100% | |

4. CONCLUSION

This research have been successfully determine the school zonation based on housing for prospective secondary school and senior high school state in Bengkulu based on the application of the results of the zonation of Voronoi diagram and Delaunay triangulation based Web GIS. The successful rate over the system reach the value of 72.05% succeed to process the school data. Furthermore, the 24.85% of unsuccessful result was because of the result of the zonation is not the result of the first level recommendation. Based on system analysis and design, implementation, and system testing, for the perfection of solving this problem there are several suggestions for future writers, namely the system can be further developed using the same or different methods or combining one method with another method to get results. which is more than expected. Furthermore, the authors hope that this system can be considered by the government to implement this zonation system for new student admissions.

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