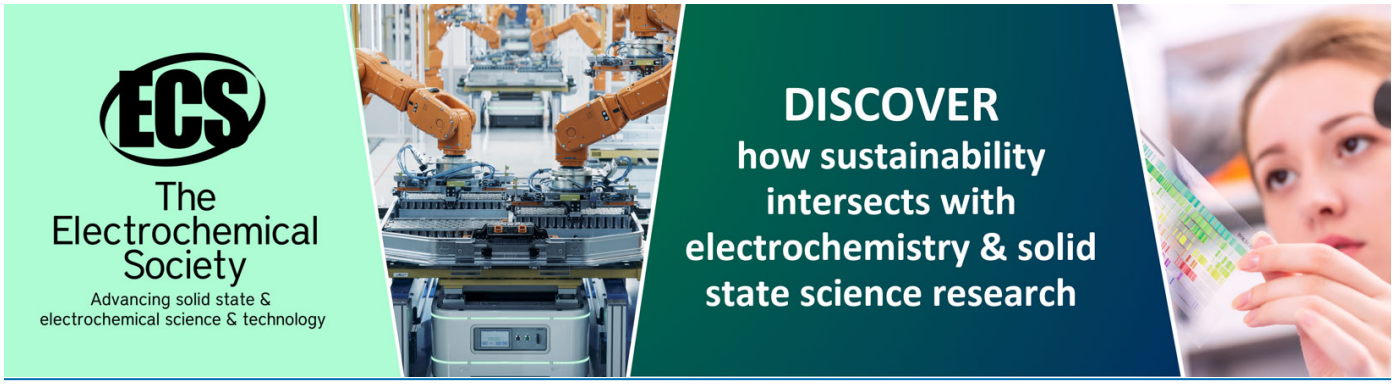
Modeling the Potential of Cereal Crops with a Smart Village-Based GIS Approach to Support Food Security



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Modeling the Potential of Cereal Crops with a Smart Village-Based GIS Approach to Support Food Security

Denny Trias Utomo[1*] , Bety Etikasari[1] , Jumiatun[2]

[1]Information Technology Department, Politeknik Negeri Jember, Indonesia
[2] Crop Production Technology Department, Politeknik Negeri Jember, Indonesia

*denny_trias@polije.ac.id

Abstract. Since 2015, government projects related to national food security have been implemented so far. This article will write a study that uses the GIS method to model the potential of food crops. The GIS web application development method uses the prototyping method with input in the form of spatial and non-spatial data which includes data on potential rice, corn, and soybeans in the Jember district, where the data was obtained from a survey at the Jember Regency Agriculture Service in the period January - August 2021 and data statistics from the book Jember in Figures 2020 and the official website of the Jember Regency BPS.

Keywords: *Geographic Information System, smart village, Food security*

1. Introduction

The development of main cereal crops needs namely rice, corn, and soybeans (pajale) for high-level domestic products has been the government's main goal since 2015. This is an effort to achieve national food security. This achievement is highly dependent on the results of agricultural production in Indonesia. One of the factors that affect agricultural production is climate change. Research shows that one of the impacts of climate change is an increasing temperature which causes a decrease in rice production from 68.1% to 92% [1]. The impact of climate change on agriculture is important, so strategies and technologies need to be applied to maintain food availability in Indonesia.

Agricultural system solutions in Indonesia must be based on data accuracy for developing information systems in this 4.0 technology era. Research shows that new technology system uses a spatial database and use artificial intelligence (AI) to generate food insecurity information [2]. From developing AI perspective based on the Territorial Information System (GIS) in obtaining data, UAV (unmanned aerial vehicle) technology can be used for collecting data spatial in the wider area [3].

Applied research internet of things has also been carried out in smart agriculture to get real-time data on agricultural land conditions [4]. The purpose of this research is the implementation of AI and internet of things technology for agriculture which is made in the smart village concept. The Smart village program was built by integrating GIS spatial data, a database of cereal crops potential by utilizing AI on a Web-based platform. The smart village concept refers to that villages can solve their problems intelligently.

2. Literature Review

2.1. Modeling the Potential of Cereal Crops

The development of superior cereal crops commodities (rice, corn, and soybeans) based on production areas can be carried out using a GIS system. Mapping of cereal crop production areas is carried out using the Hot Spot Getis-Ord Gi* analysis method to recommend the potential of superior cereal crops in a specific area [5]. The modeling system for cereal crop production potential is influenced by several factors. So proper data and analysis are required during implementation. After doing an analysis of potential soil fertility and climate in a specific area, so that area can develop a cereal cropping system itself. Plant growth and production factors become the focus of studies to develop modeling systems. The results showed that the significant factor effect was harvested area and rainfall [6].

2.2. Smart Village-Based GIS Approach to Support Food Security

The smart village concept in this study is the application of modern agricultural technology in the specific area so the conventional agricultural systems and have less measurable results can be optimized using several technological approaches such as Geographic Information System (GIS), Decision Support System (DSS)[7]–[9].

GIS is a computer-based system that is used to store and manipulate geographic information. Geographic information system aims to collect, store and analyze objects or phenomena where geographic location is an important characteristic for analysis. GIS illustrated into a map form. It becomes an effective presentation tool and geographical data storage. The stored information will be processed and presented by changing the presentation form, a map always provides images or symbols of geographic elements with a fixed or static shape even though it is for different needed [5], [7], [8], [10].

This research is the first step for the studies series development that integrates GIS with DSS. The integration of data input into the GIS system will produce useful information that will be used for the next research to develop DSS where one system that applied to the Smart Village concept is collecting data in real-time so that the information provided to farmers is accurate.

3. Methods

These research stages use the prototype method for the software development stage. The stages include system requirements analysis, system design, system design evaluation, system coding, and alpha version system testing by the team. The prototype method is shown in Figure 1

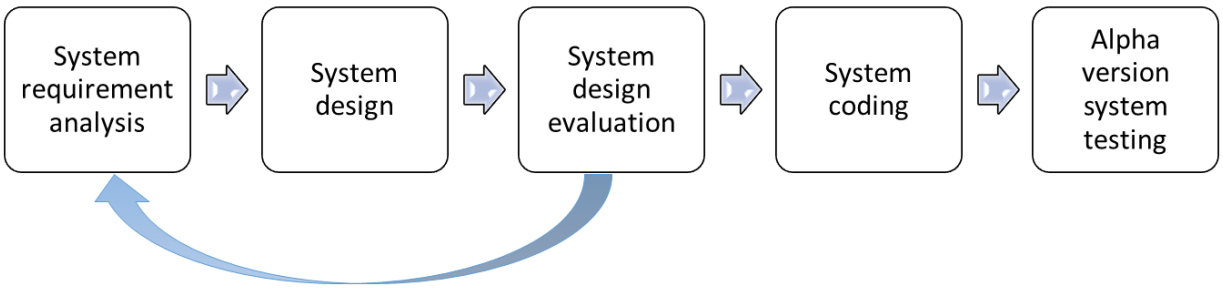

Figure 1. Prototype Method for System Development

The reason for using the prototype method is because the designing system of GIS, DSS, and aerial images for the smart village concept is complex. This smart village concept needs an evaluation stage during the coding stage for the system to become easier [11].

3.1. System requirement analysis

The system requirement analysis stage is done by using observation, interview, and documentation techniques. Observations and interviews were conducted with several farmers in Jember Regency. Observation and interview technique purpose to comparative data from the Badan Pusat Statistik (BPS)

documentation to complete the data needed. The secondary data documentation technique from BPS was taken from the Jember Regency Book in 2020.

3.2. System design

The system design stage is done by using an image processing application like diagram.net and adobe illustration. Prototyping is made according to the business process of the GIS concept the smart village that will be developed. The flowchart of the GIS application is shown in Figure 2.

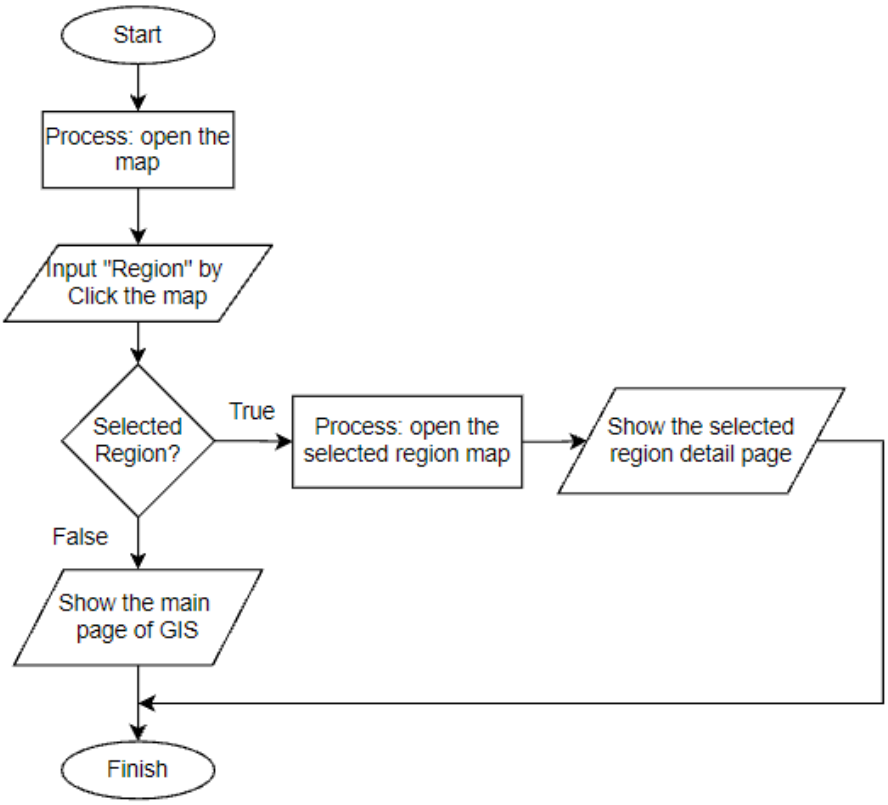

Figure 2. Flowchart of Web GIS

3.3. System design evaluation

The system design evaluation stage purpose to test the results of the prototype that has been developed. This is to determine whether there is still a need for a redesign before the system coding stage is done.

3.4. System coding

The system coding stage of the GIS system is done using PHP programming with Laravel framework, MySQL database, composer, and Github. The coding of then is system is done according to the prototype that has been developed in the system design stage.

3.5. Alpha-version system testing

The alpha version system testing stage is done using the User Acceptance Test (UAT) method. Testing is done on users who have contributed to agriculture. The form of the instrument used is a questionnaire with 5 answer choices on the Likert scale.

4. Result and Discussion

This section discusses applications development according to the research stage described in the Methods section above and also discusses the verification testing of an application program. The web-based GIS application prototype that has been developed can be accessed on the webpage https://www.smart-agrotech.com/ page.

4.1. Application development

The application development stage had two stages. The first stages are making a logical database design and physical database then the second stage is making a complete application. The logical database is shown in Figure 3 and the physical database is shown in Figures 4 to 13.

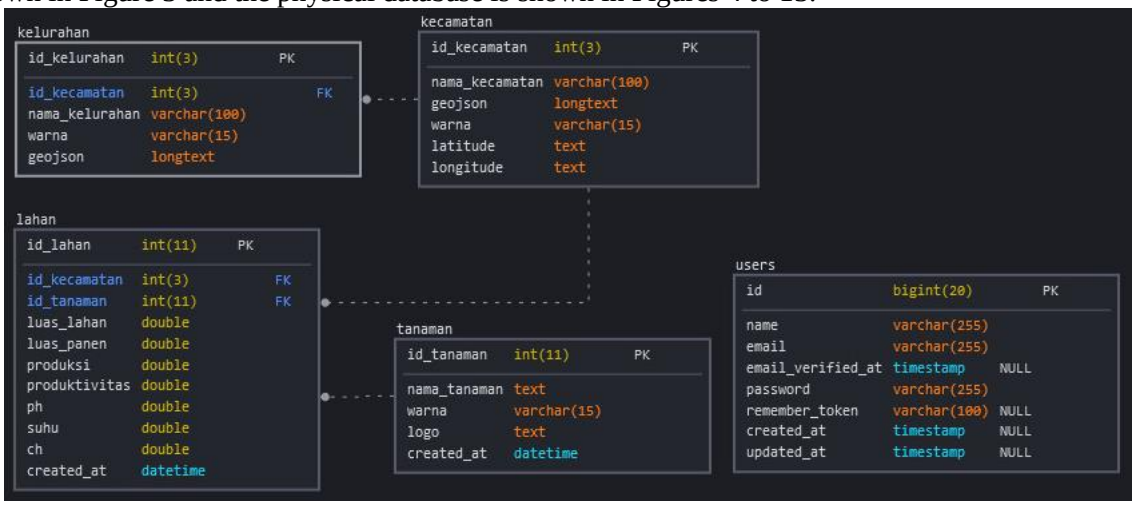

Figure 3 Database Diagram Design

Figure 3 shows the logical database is consists of 4 main tables that are interconnected with each other, namely the "lahan" table, "tanaman" table, "kecamatan" table, and "kelurahan" table. The "tanaman" table and the "kecamatan" table have a relation to "lahan" table which linked by primary key and foreign key, namely id_tanaman and id_kecamatan. The "kecamatan" table has a relation to "kecamatan" table which linked by the primary key and foreign key id_kecamatan. In addition, there is one table that is used to store user data, namely the "users" table. This logical database was made from the database design stage and fulfill the normalization principle.

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
☐	1	**id_kecamatan** 🔑	int(2)			No	*None*		AUTO_INCREMENT	Change Drop More
☐	2	**nama_kecamatan**	varchar(100)	utf8mb4_general_ci		No	*None*			Change Drop More
☐	3	**geojson**	longtext	utf8mb4_bin		No				Change Drop More
☐	4	**warna**	varchar(15)	utf8mb4_general_ci		No	*None*			Change Drop More
☐	5	**latitude**	text	utf8mb4_general_ci		No				Change Drop More
☐	6	**longitude**	text	utf8mb4_general_ci		No				Change Drop More

Figure 4. Table structured in "kecamatan" table

	id_kecamatan	nama_kecamatan	geojson	warna	latitude	longitude
Edit Copy Delete	1	Kecamatan Ajung	{"type":"Polygon","coordinates":[[[113.68484462797...	#ffffff	-8.222823118407701	113.64428354002413
Edit Copy Delete	2	Kecamatan Ambulu	{"type":"MultiPolygon","coordinates":[[[[113.58284...	#ffffff	-8.345758650256132	113.60599757220882
Edit Copy Delete	3	Kecamatan Arjasa	{"type":"Polygon","coordinates":[[[113.77298165897...	#ffffff	-8.111865195115351	113.73682662631333
Edit Copy Delete	4	Kecamatan Balung	{"type":"Polygon","coordinates":[[[113.56882607386...	#ffffff	-8.27489299490978	113.53416051601032
Edit Copy Delete	5	Kecamatan Bangsalsari	{"type":"Polygon","coordinates":[[[113.60432420090...	#f4a100	-8.17754309803353	113.53837712042558
Edit Copy Delete	6	Kecamatan Gumukmas	{"type":"Polygon","coordinates":[[[113.45697000036...	#ffffff	-8.297230818583614	113.41630748651455
Edit Copy Delete	7	Kecamatan Jelbuk	{"type":"Polygon","coordinates":[[[113.78410960377...	#ffffff	-8.088837149671866	113.74944411466343
Edit Copy Delete	8	Kecamatan Jenggawah	{"type":"Polygon","coordinates":[[[113.69814999962...	#ffffff	-8.25841485294082	113.67433161705121
Edit Copy Delete	9	Kecamatan Jombang	{"type":"Polygon","coordinates":[[[113.39992999957...	#ffffff	-8.24456928429861	113.36541327037854
Edit Copy Delete	10	Kecamatan Kalisat	{"type":"Polygon","coordinates":[[[113.83298999988...	#ffffff	-8.12707487834376	113.80927658419
Edit Copy Delete	11	Kecamatan Kaliwates	{"type":"Polygon","coordinates":[[[113.70537982132...	#00ac69	-8.179242253752724	113.66609441363838
Edit Copy Delete	12	Kecamatan Kencong	{"type":"Polygon","coordinates":[[[113.38194999959...	#ffffff	-8.262491983089246	113.38058448631998
Edit Copy Delete	13	Kecamatan Ledokombo	{"type":"Polygon","coordinates":[[[113.85873834369...	#ffffff	-8.140839569527067	113.87605003732726
Edit Copy Delete	14	Kecamatan Mayang	{"type":"Polygon","coordinates":[[[113.85012142476...	#ffffff	-8.188842347461605	113.80026357111404
Edit Copy Delete	15	Kecamatan Mumbulsari	{"type":"Polygon","coordinates":[[[113.78578999960...	#ffffff	-8.285255184891327	113.75321814660737
Edit Copy Delete	16	Kecamatan Pakusari	{"type":"Polygon","coordinates":[[[113.77142679501...	#ffffff	-8.179836956543436	113.76249208254312

Figure 5. Data in "kecamatan" table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	id_kelurahan	int(3)			No	None		AUTO_INCREMENT	Change Drop More
2	id_kecamatan	int(3)			No	None			Change Drop More
3	nama_kelurahan	varchar(100)	utf8mb4_general_ci		No	None			Change Drop More
4	warna	varchar(15)	utf8mb4_general_ci		No	None			Change Drop More
5	geojson	longtext	utf8mb4_general_ci		No				Change Drop More

Figure 6. Table structured in "kelurahan" table

id_kelurahan	id_kecamatan	nama_kelurahan	warna	geojson
Edit Copy Delete	2	21	SIDOMULYO	#86B4D7	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	4	2	KASIYAN TIMUR	#88073f	{"type":"MultiPolygon","coordinates":[[[[113.30101...
Edit Copy Delete	5	9	PADOMASAN	#594370	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	6	9	SARIMULYO	#39e221	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	8	12	PASEBAN	#9b6693	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	9	12	KENCONG	#baef82	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	10	12	WONOREJO	#745514	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	11	25	JAMINTORO	#da2c43	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	12	25	JATIROTO	#52dadc	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	13	25	YOSORATI	#c05180	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	14	23	UMBULSARI	#561fe7	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	15	19	WONOSARI	#0a0366	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	16	25	PRINGGOWIRAWAN	#2ba1e7	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	17	6	TEMBOKREJO	#e7f9df	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	18	6	PURWOASRI	#da0d13	{ "type": "Feature", "properties": { "KECAMATAN": ...
Edit Copy Delete	19	6	BAGOREJO	#0f43b0	{ "type": "Feature", "properties": { "KECAMATAN": ...
Console Copy Delete	20	6	KARANGREJO	#fc3ffa	{ "type": "Feature", "properties": { "KECAMATAN": ...

Figure 7. Data in "kelurahan" table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	id_lahan	int(11)			No	None		AUTO_INCREMENT	Change Drop More
2	id_kecamatan	int(11)			No	None			Change Drop More
3	id_tanaman	int(11)			No	None			Change Drop More
4	luas_lahan	double			No	None			Change Drop More
5	luas_panen	double			No	None			Change Drop More
6	produksi	double			No	None			Change Drop More
7	produktivitas	double			No	None			Change Drop More
8	ph	double			No	None			Change Drop More
9	suhu	double			No	None			Change Drop More
10	ch	double			No	None			Change Drop More
11	created_at	datetime			No	None			Change Drop More

Figure 8. Data structure in “lahan” table

	id_lahan	id_kecamatan	id_tanaman	luas_lahan	luas_panen	produksi	produktivitas	ph	suhu	ch	created_at
Edit Copy Delete	5	5	4	0	8080	51693	63.97	7	0	0	2021-09-08 20:51:37
Edit Copy Delete	8	12	4	0	6689	42958	64.23	0	0	0	2021-09-15 17:14:29
Edit Copy Delete	9	6	4	0	6885	45567	66.19	0	0	0	2021-09-15 17:27:56
Edit Copy Delete	10	19	4	0	5912	39853	67.41	0	0	0	2021-09-15 17:28:28
Edit Copy Delete	11	31	4	0	4731	35798	75.67	0	0	0	2021-09-15 17:28:55
Edit Copy Delete	12	2	4	0	3633	26004	71.58	0	0	0	2021-09-15 17:30:24
Edit Copy Delete	13	29	4	0	3441	21426	62.26	0	0	0	2021-09-15 17:31:01
Edit Copy Delete	14	22	4	0	4411	24319	55.13	0	0	0	2021-09-15 17:36:04
Edit Copy Delete	15	14	4	0	4976	30016	60.32	0	0	0	2021-09-15 17:36:33
Edit Copy Delete	16	15	4	0	6128	37714	61.54	0	0	0	2021-09-15 17:36:58
Edit Copy Delete	17	8	4	0	6934	47096	67.92	0	0	0	2021-09-15 17:37:35
Edit Copy Delete	18	1	4	0	7681	48446	63.07	0	0	0	2021-09-15 18:08:31
Edit Copy Delete	19	26	4	0	6654	40191	60.4	0	0	0	2021-09-15 18:10:15
Edit Copy Delete	20	4	4	0	5666	39466	69.65	0	0	0	2021-09-15 18:11:10
Edit Copy Delete	21	23	4	0	3078	19082	62	0	0	0	2021-09-15 18:11:41
Edit Copy Delete	22	21	4	0	4781	28625	59.87	0	0	0	2021-09-15 18:12:32
Console Copy Delete	23	9	4	0	6775	35719	52.72	0	0	0	2021-09-15 18:13:05

Figure 9. Data in “lahan” table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	id_tanaman	int(11)			No	None		AUTO_INCREMENT	Change Drop More
2	nama_tanaman	text	utf8mb4_general_ci		No				Change Drop More
3	warna	varchar(15)	utf8mb4_general_ci		No	None			Change Drop More
4	logo	text	utf8mb4_general_ci		No				Change Drop More
5	created_at	datetime			No	None			Change Drop More

Figure 10. Data structured in “tanaman” table

	id_tanaman	nama_tanaman	warna	logo	created_at
Edit Copy Delete	4	Padi	#f4a100	assets/tanaman/1gRJvhe1zH.png	2021-06-18 10:35:44
Edit Copy Delete	5	Jagung	#f76400	assets/tanaman/XKpS7ppDSU.png	2021-06-19 11:35:31
Edit Copy Delete	6	Kedelai	#00ac69	assets/tanaman/2eFLoE53Of.png	2021-06-19 11:38:24

Figure 11. Data in “tanaman” table

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	id	bigint(20)		UNSIGNED	No	None		AUTO_INCREMENT	Change Drop More
2	name	varchar(255)	utf8mb4_unicode_ci		No	None			Change Drop More
3	email	varchar(255)	utf8mb4_unicode_ci		No	None			Change Drop More
4	email_verified_at	timestamp			Yes	NULL			Change Drop More
5	password	varchar(255)	utf8mb4_unicode_ci		No	None			Change Drop More
6	remember_token	varchar(100)	utf8mb4_unicode_ci		Yes	NULL			Change Drop More
7	created_at	timestamp			Yes	NULL			Change Drop More
8	updated_at	timestamp			Yes	NULL			Change Drop More

Figure 12. The data structure in the "users" table

Options

	id	name	email	email_verified_at	password	remember_token	created_at	updated_
Edit Copy Delete	1	Yudha	yudha@gmail.com	NULL	$2y$10$90X4SqLeXPYJuuNOiShIVOcagkFYqU/XT0IgCbnC2TA...	NULL	2021-06-12 02:55:13	2021-06-

Figure 13 The data in the "users" table

In addition to building the application databases, a GIS website is also built. The GIS website that has been developed consists of two main pages, namely the main page which contains maps of all areas of Jember Regency, and the detailed land view page which contains detailed data for each region. On the main page, a map of Jember Regency is displayed by labeling the first layer, when the label is clicked, the user can see detailed data about the conditions in the specific district. On the map, there are also different colored markings in 3 areas which are the focus of research conducted this year, namely Bangsalsari District, Panti District, and Kaliwates District. The color of the area according to the "legend" on the map that yellow indicates rice commodities, orange indicates corn commodities, and green indicates soybeans commodities.

The data displayed in this GIS get from Badan Pusat Statistik of Jember Regency and observation with farmers. The purpose of observation to farmers is to ensure that the data are real by actual field conditions. Therefore, the focus of detailed data displayed in this web GIS is still from one location point in the 3 sub-districts. In addition to the map, this home page also displays data on total harvested area, data on total rice harvested area, total corn harvested area, and total soybean harvested area. The initial view of the GIS web page is shown in Figure 14.

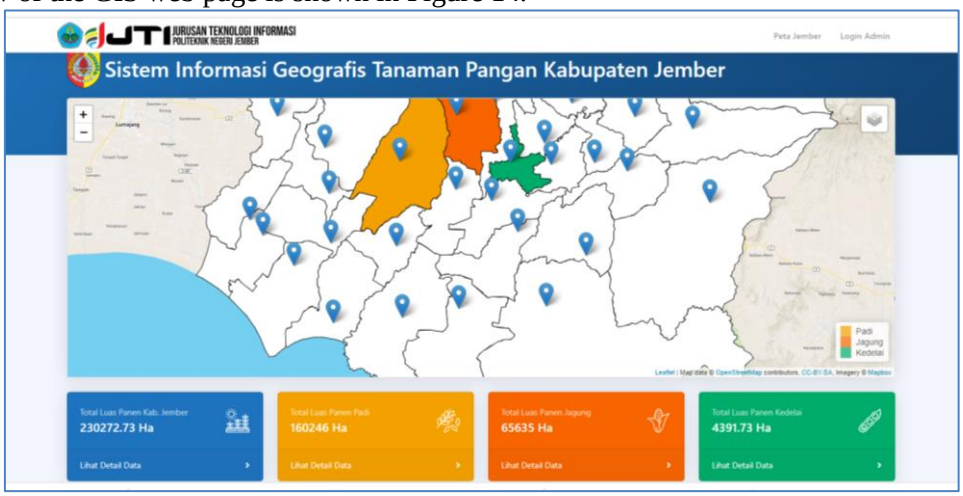

Figure 14. Main Page of WebGIS

The data detail page displays detailed sub-district data including harvested area, production, productivity, average temperature, soil pH, drainage, and soil texture. In addition, it also displays data on harvested area, production, and productivity for each cereal crop that can be produced. The data detail page display is shown in Figure 15.

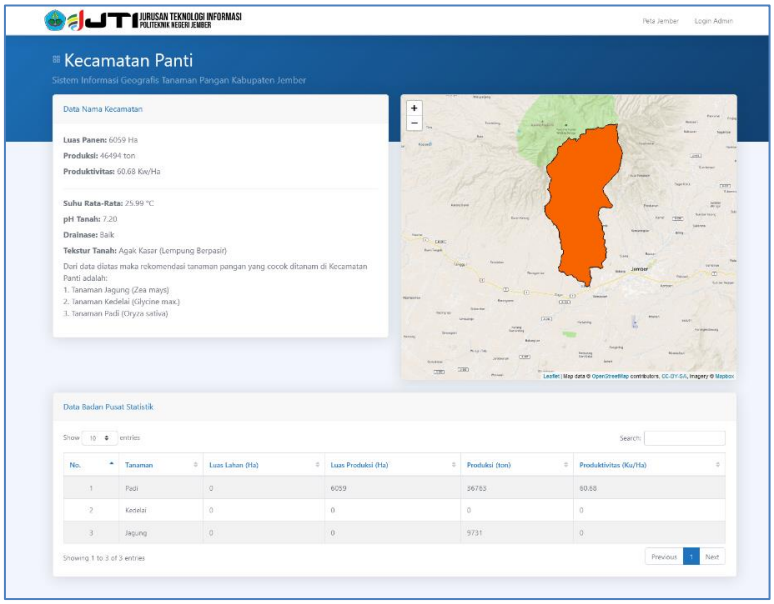

Figure 15. Data detail page displays of each district

4.2. Verification result and application testing

In the final stage of this research, testing and verification of this Web GIS application were done using the User Acceptance Testing method [12] [13] [14] [15] [16]. The test instrument was done using the google form as shown in Figure 16.

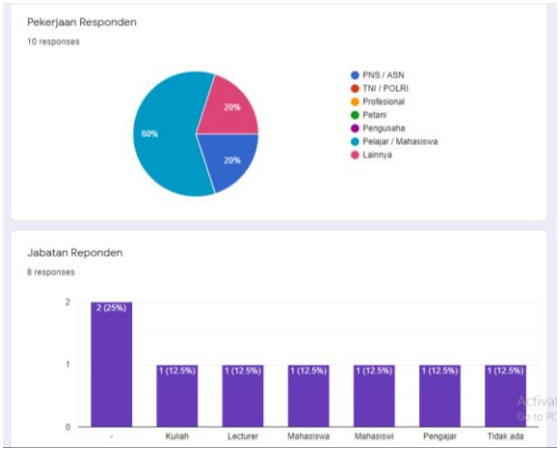

Figure 16. Verification using User Acceptance Testing in WebGIS

This test uses the Linkert scale because based on several papers it is shown that to verify web applications, you can use a the Likert scale [17]–[25] with scoring rules as shown in Table 1.

Table 1. Linkert scale in WebGIS Smart Village Evaluation

No	Linkert scale		Score
1	Very Complete	Very Simple	5
2	Complete	Simple	4
3	Quite Complete	Quite Easy	3
4	Less Complete	Less Easy	2
5	Incomplete	Not Easy	1

Based on the questionnaii\re instrument, the testing result is shown in Table 2.

Table 2. Verification Result of User Acceptance Testing

No	Question	Very complete	Complete	Quite Complete	Less complete	Incomplete	Score %
		Very Simple	Simple	Quite Easy	Less Easy	Not Easy	
		5	4	3	2	1	
1	Is the appearance of each sub-district location in Jember Regency on this geographic information system website complete according to the map?	24,4	31,7	36,6	7,3	0	100
2	Is the map display easy to identify each sub-district name with a color label?	34,1	34,1	24,4	7,3	0	100
3	Do you find it easy when you “want to see detailed data on total production land in Jember Regency on the geographic information system web”?	32,5	42,5	12,5	7,5	5	100
4	Do you find it easy when you “want to see detailed data on total rice land in Jember Regency on the geographic information system web”?	36,6	29,3	17,1	12,2	10	100
5	Do you find it easy when you “want to see detailed data on total maize land in Jember Regency on the geographic information system web”?	39	26,8	22	7	4,9	100
6	Do you find it easy when you “want to see detailed data on total soybean land in Jember Regency on the geographic information system web”?	37,65	32,5	20	5	5	100
7	Do you find it easy when you “want to find recommendations for plants that can be grown in your area of planting”?	29,3	39	14,6	12,2	2	100
8	Do you find it easy to “find cropping characteristics such as soil pH, average temperature, drainage, and soil texture in your area in the application”?	29,3	22	34	9,8	4,9	0

No	Question	Very complete	Complete	Quite Complete	Less complete	Incomplete	Score %
		Very Simple	Simple	Quite Easy	Less Easy	Not Easy	
		5	4	3	2	1	
9	Do you find it easy to "find production data for rice, soybeans, and maize in certain areas in this application"?	34,1	31,7	22	7,3	4,9	0
10	Does this application have an attractive appearance?	26,8	17	22	7,3	2,4	0

Based on the results of an online survey by Google Form application with 41 respondents, the following results show that: "Very Simple" and "Simple" or "very Complete" and "Complete" 80%, this indicates that the application or web that built in this study under user expectations (Verified).

5. Conclusion

This research produces another solution in agriculture to increase the production of cereal crops. Modeling the potential of cereal crops based on Web GIS in smart villages which in detail can be concluded that the Web GIS application for modeling the potential of web-based food crops by integrating the database in the display design can be developed and the results of the trial of the web GIS application using the User Acceptance method. The testing online survey results using the Google Form show that "Very Simple" and "Simple" or "Very Complete" > 80%, this indicates that the application or web that built in this study is under user expectations (Verified).

6. Suggestion

This research still requires development and improvement, including the following: (1) applicable suggestions aimed at the industry: considering that the developed application is still a prototype, it is better then this application be further developed into a professional application that will benefit the agricultural industry in Indonesia, and (2) academic suggestions for further research is that further research is needed to test the possibility of this GIS system prototype in other districts outside Jember Regency and further research is needed that can provide added value to the information generated by this GIS, such as DSS for cereal crop modeling that is most suitable in certain areas that collecting data from IoT integrated big data.

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