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MODEL RULE-BASED EXPERT SYSTEM FOR FIRE STATION ALLOCATION ASSESSMENT: APPLIED IN KENDARI CITY, INDONESIA

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ABSTRACT

Kendari City is an urban region with the smallest area as well as the largest population in Southeast Sulawesi. Fires in Kendari City had rather frequently occurred and caused numerous materials loss. The amount of fire station in Kendari city is very limited, that is, one station is to serve all urban areas, as well as the the slow respond of the time service of firefighters, ≥15 minutes since the fire is started. The aim of this study is to develop an urban model of fire station allocation assessment. The model is developed by using Expert Systems with the Geographic Information System (GIS). The results show that the fire station chosen locations, i.e. (1) Suitable I, consists of grid no. 1268 and 1337, (2) Suitable II, amounting to 33 grids, and (3) Suitable III, amounting to 14 grids. The fire station allocation should be appropriately close to the high risk of the fire area, located on the arterial road and near with the potential water resources.

Keywords: *Urban Fire, Expert System, Fire Risk, Fire Station, GIS*

1. INTRODUCTION

Development and growth of urban areas in Indonesia have increased every year. This can be seen by the increasing of urban areas, the new growth centres, and the number of population living and activity in an urban area. Currently, it is about 53 percent of Indonesian are into urban community and living in the urban area [10]. Generally, the driving factors for urban area development are the increasing of population, and car ownership naturally [15, 18], also by the migration process. These factors impact on the urban itself, namely the increasing demand on the public service facility and infrastructure, service and trade service facility, transportation infrastructure [15, 17], clean water, clean air [14] and other infrastructures. The urban population growth also impacts on the change in land use, population density, transportation demand [15], entertainment, increasing traffic accident [16], air pollution [14], security and other aspects.

The general reality of urban development in Indonesia nowadays is the physical growth of urban space not supported by environment carrying capacity, strict devices, and regulation. These lead to the uncontrolled urban growth and development. The appropriate urban spatial will create harmony between natural environment and artificial environment as well as the protection on spatial function and prevention on negative impacts on the environment caused by urban spatial utilization. The urban spatial will also increase the area ability or decrease its vulnerability on various possible negative risks, either naturally or non-naturally.

One of the important aspects and often neglected in urban and area spatial is the planning. Indonesia is a country with a disaster potency because geographically, the area is located in the equator area having morphology with various lands until high mountains, the movement activity of active tectonic plate around the Indonesian seas, so that it creates earthquake track, series of active volcanoes and geological fault as earthquake and landslide-prone areas. The disaster potency includes the main hazard potencies, such as earthquake, landslide, volcano eruptions, tsunami, flood, and collateral

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hazard potencies such as fire, epidemic, and social conflict. The highest potencies of collateral hazard are in the urban area having high population density, land use complexity, urban population activity centre, building materials and urban slum areas.

The high risk of urban area in Indonesia on the disaster can be seen from the area vulnerability, including the physical area vulnerability, social and economic population. The physical vulnerability describes the estimation of damage level on the environment facility and infrastructure if there are any certain hazardous factors, in social and economic population aspects related to the community capacity and condition in facing disasters. Fire is one of the disasters often found in urban area, mainly in the area of dense population or high activity such as commercial area. These kinds of areas contribute to the increasing of vulnerability on urban fire. The danger risk of urban fire can be decreased by good urban planning concepts, such as efficient land use and the road system supporting on the accessibility of fire engine [3].

Kendari City is one of the cities with great number of population in Southeast Sulawesi Province. In 2014, the population reached 335.889 inhabitants, where the average of population growth per year is 3.51 percent. Kendari City has the smallest regional area, only 295,89 Km2, or 0,78 percent from the total area of the Province [2].

A large number of population by relatively small regional area has bigger potential on urban environmental problems, such as building density, disorderly of land use, bad sanitation, improper road facilities, and the arising temporary semi-permanent or urgent buildings. Mantra [9] wrote that the vulnerability on the fire disaster including the environment condition (width of the entrance, availability of community field/parking lot), building materials, building structures and inter-building distances.

The fire disaster in Kendari City is frequent and cause lot of materials loss. One of the biggest incidents was in PT. Daka Samudera in 2015, fire in the building of the company caused losing billion rupiah. The firefighters arrived 15 minutes after the warning of the fire [4]. The high urban city intensity and risk level in Kendari City is mostly caused by the very limited number of firefighters' station; one station is to serve all urban areas, as well as the slow respond of the time service of firefighter, ≥15 minutes since the fire is started.

Table 1: Fires History On 2012-2016 In Kendari City [4]

Years	Caused	Fire Types	Materials Loss and Fatalities
2012	Candle lamps, electrical short circuist, fireworks, bursting stove, mosquito coils, garbages burning, fireplace, undetected	Blady grass, storehouses, kiosks, cooperations, stalls, markets, coconut trees, residences, shop houses	IDR 22.493.500.000 Fatality: None
2013	Electrical short circuit, bursting stoves, mosquito coils, land combustion, garbage burning, stub, fuel oil spilled, fireplace, burnt by person, undetected	Blady grass, machine shop, hotel, office, kiosk, car, market residence, shophouse, place of business	IDR 24.227.000.000 Fatality: None
2014	Candle lamp, electrical short circuit, bursting stove, oil overflowed, land combustion, garbage burning, stub, gasometer, undetected	Blady grass, bulk asphalt, tire, warehouse, company building, worker base camp, machine shop, powerhouse, generator, storehouse, office, homestead garden, kiosk, peatland, sago trees, car, motorcycle, crackers factory, market, residence, shophouse, garbage, bunk, woodpile	IDR 21.679.500.000 Fatality: 2 people (pass away)
2015	Electrical short circuit, fuel pipe leakage, regulator hose leakage, fireworks, mosquito coils, land combustion, garbage burning, stub, piece of electrical weld, fireplace, undetected	Blady grass, warehouse, company building, worker base camp, machine shop, powerhouse, storehouse, college, office, homestead garden, kiosk, peatland, sago trees, car, market, hospital, school, residence, shophouse, garbage, gasometer, weld tube, woodpile, sawmill, shrubland	IDR 141.724.500.000 Fatality: None
2016, inclusive to August	Electrical short circuit, gas leakage fireworks, bursting stove, gas explosion,	Blady grass, powerhouse, motor boat, kiosk, peatland, school, residence, shophouse,	IDR 10.225.000.000 Fatality: 1 person (injured)

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Years	Caused	Fire Types	Materials Loss and Fatalities
	land combustion, garbage burning, stub, undetected	barbershop, gasometer	

The previous research on a comparison of fire service response time on the number of firefighter station in Dubai shows that the 5 (five) minute response time requires 13 stations, 4 (four) minute response time requires 20 stations and 3 (three) minute response time requires 25 stations [1]. Murray [11], described the urbanest area in California had service standard, the firefighters arrived on the incident location with 9 minute response time since the fire. This is addressed that the protection on urban fire disaster must be done by the quick response.

The standard of fire response time according to NFPA [12] is four minutes (240 seconds) or less for the arrival of the first arriving engine company at a fire suppression incident and/or eight minutes (480 seconds) or less for the deployment of a full first alarm assignment at a fire suppression incident.

This research is an important and urgent step that must be done because the intensity of fire incident along with the impact that occurred in Kendari City until now is higher and has caused many losses. This research will produce a model of disaster risk assessment and fire station allocation which is an urban fire disaster mitigation effort as an innovation of knowledge and technology. The modeling is an effort to prevent, mitigate and increase preparedness in fire disaster management in Kendari City to face disaster incident or minimize risk and impact of disaster that may be caused so that fire incident can be anticipated, not fatal and repetitive.

The strength of risk, damage and impact of losses caused by the fire disaster make this research as part of the fire disaster mitigation solution, which is expected to result in the development of spatial model of urban areas that can provide protection for its citizens against the threat of fire, eliminate the causes of threat, reduce potential hazards, reduce vulnerability and increase capacity for physical elements of disaster risk areas.

2. THE MATERIALS AND METHODS

The high urban population activity leads to the bigger opportunity of fire in the urban area. The general conditions including physical, social economic and political factors are one of the potencies for a group of the community to be more vulnerable to get a disaster.

Toki et al [13] stated that most fire in dense areas in urban area relates to human habits or behaviours, but the fire disaster risk can be reduced or eliminated overall by the availability of appropriate environmental infrastructures, such as the availability of hydrants in dense residence area. Murray [11] wrote that all of the urban areas must be protected from fire disaster hazard; the firefighters must give rapid responses and services. The fire station services have long been a prerequisite in the availability of urban facilities. The use of service response time standard by the fire station tries to reduce the risk of human and properties loss.

Mantra [9] mentioned that in order to overcome the fire hazard, it is necessary to know to the fire flame time and amount to know the mean response time required to extinguish the fire before it burns combustible building materials passed by the fire. The stage of appropriate fire development to extinguish and reduce the losses is the transition era between the growth stage and flashover stage.

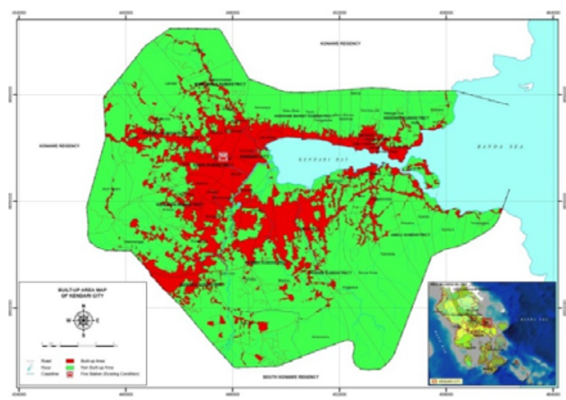

Figure 1: The Built-Up Area Map Of Kendari City, 2016

Expert systems are computer programs that apply artificial intelligence to narrow and clearly defined problems. They are named for their essential characteristics: they provide advice in problem-solving based on the knowledge of experts. Expert systems typically combine rules with facts to draw conclusions; the process relies heavily on theories of logical deduction. Both heuristic methods and conventional computer programs (e.g., FORTRAN programs) are often used in expert systems. The subject area of an expert system, such as site planning or zoning administration, is called its domain. The collection of facts, definitions, rules of thumb, and computational procedures that apply to

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the domain is called its knowledge base. Sources of that knowledge include published materials, quantitative analysis programs, and the intuitions and problem-solving strategies of experts in the subject area [8].

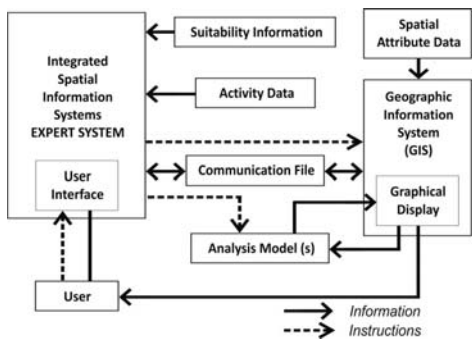

Figure 2: The Expert System Model Procedure [8]

Furthermore, Kim et al [8] described that the expert system for site selection has been designed to aid land use planners, developers, or prospective land users. The system helps a user develop a set of site attributes and determine their weighted relative importance. The site selection knowledge base of the expert system consists of four parts: the knowledge acquisition, induction, design, and decision analysis units.

The knowledge acquisition unit is used to collect and organize information provided by expert decision makers. The induction unit evaluates this information and generates rules and entity evaluation functions expressing the expert judgment. The decision unit uses the rules generated by the induction module and employs decision theory techniques for selecting one or more of the available alternatives.

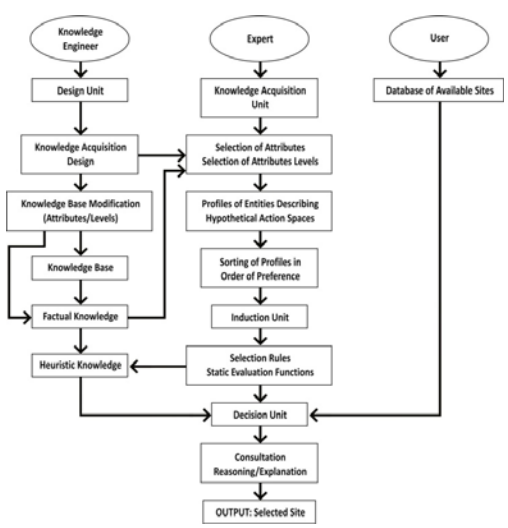

Figure 3: Expert System Schematic Structure For Site Selection [8]

The major research area for artificial intelligence includes natural language processing, symbol processing, rule-based system and logic systems. The development of functional expert systems is always centered on the organization of a knowledge base. Knowledge engineers collect and organize knowledge gathered from domain expert then convert the expert knowledge into a form which computer expert system understands and save that converted knowledge into the knowledge base. Users enter the collected facts into the system via the user interface and save the data into the fact base. Finally, users get the results, recommendations, and explanations from the system [7].

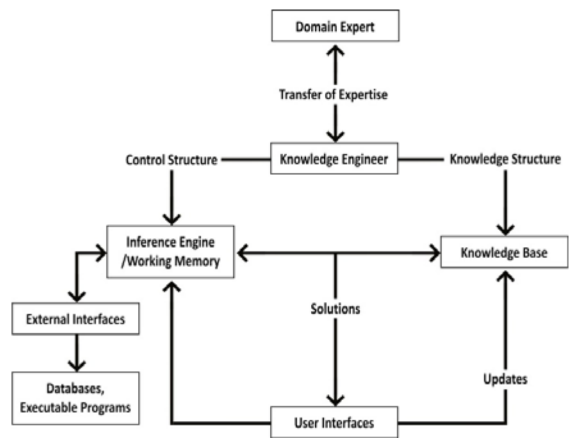

Figure 4: Expert System Component [7]

Study about urban fire station site was done by expert system approach method. This expert system came from the knowledge-based expert system, i.e. a system using human knowledge which then was inserted into the computer to solve the problem that generally needs an expert’s expertise. This expert system procedure works by imitating knowledge and thinking the process of an expert in solving the complicated problem.

The system designing uses hardware, i.e. personal computer (PC) or notebook and software, i.e. Geographic Information System (GIS) application (ArcGIS, ArcView, Quantum GIS, etc.), Fortran and Quick Basic. This system was operated in Microsoft Windows Operation System.

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Figure 5: Expert System Model For Urban Fire Station Selection In Kendari City

The development of GIS has provided a powerful tool for managing and solving emergency management problems. GIS is a professional computer system for collecting, storing, managing, retrieving, transforming, analyzing, and displaying of spatial data. It can be used for many kinds of purpose in both macro and micro scales. GIS was designed to support geographical inquiry and, ultimately, spatial decision making. Especially in the natural disaster area, GIS has been applied in the simulation and early warning system, emergency management system, and disaster damage assessment, etc. [5]. GIS approach can be assessed for the fire risk, based on historical and current data and translated under cartographic shape, can be a remarkable contribution to the forest managers and a tool for a better preventive decision, based on the logical basis. Indeed, these cartographic documents of the degree of risk reveal sectors of high sensibility at the fire risk [6].

Substances used in this urban fire station research were obtained from several sources which covered primary and secondary data. Primary data was obtained from field survey activity, included data about land use, building material types, and potential water source location. Secondary data included satellite imagery, administration boundaries map, forest area status map, road hierarchy map, etc. Apart from those two, we also use our own analytic data i.e. GIS grid based map (amount 4529 grids, each 250 m x 250 m or 62.500 m2) and a map of high-risk fire area based on the grid.

3. RESULT AND DISSCUSSIONS

3.1 Urban Fire Risk

The urban fire risk was analyzed by determining factors which influence urban fire rate, i.e. combustible or non-combustible building material, building density, whether the area was crossed by arterial or collector road, and the distance from the potential water source.

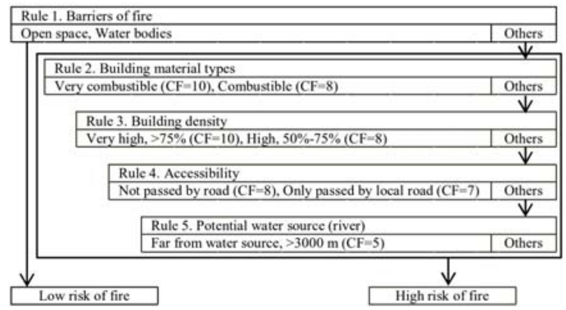

Figure 6: Chart Of Rules System For Urban Fire Risk In Kendari City

Every influencing factor was then given weight based on its influence on fire risk, in the form of Certainty Factor (CF). Those factors were then made into a knowledge represented method i.e. risk rule in the form of the pair of condition-action or if-then. Risk rule is stated as an implication of two part i.e. “if” part and “then” part. If “if” part is fulfilled, then “then” part will be valued as right. If “if” part is not fulfilled, then “then” part will be shifted to the following “then” part.

The fire risk in Kendari City, was rated by expert system approach by using GIS Grid shows the risk degree which was then classified into four classes, i.e. (1) Very high risk, amounting to 586 grids, (2) High risk, amounting to 441 grids, (3) Low risk, amounting to 1861 grids, (4) Very low risk, 1641 grids. The influencing factors of fire risk rate are: (1) area infrastructure, included road dimension and fire engine accessibility, and water source for firefighting, included hydrant, (2) building material type, included combustible and non-combustible building, (3) response time service of firefighting.

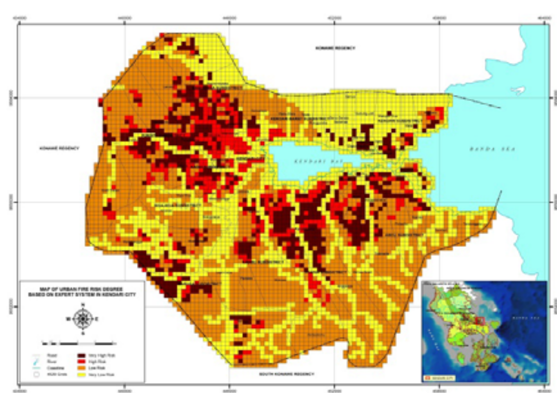
Figure 7: Map Of Fire Risk Degrees Based On Expert System Model In Kendari City

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3.2 Fire Station Allocation

Fire station location determination was based on several supporting factors i.e. it's near with high risk of the fire area, being crossed by arterial and collector road, the distance from the potential water source (<3000 m), and categorized as the unused area.

In addition to supporting factors, the analysis was also conducted to several inhibiting factors in fire station allocation, i.e. natural disaster area, conservation area, slope degree >15%, restricted area, school zone, and worship area. Supporting factors are scored, range from lowest score 4 (CF=4) to highest score i.e. 10 (CF=10). While inhibiting factors are scored 1 if it exists and 2 if it doesn't.

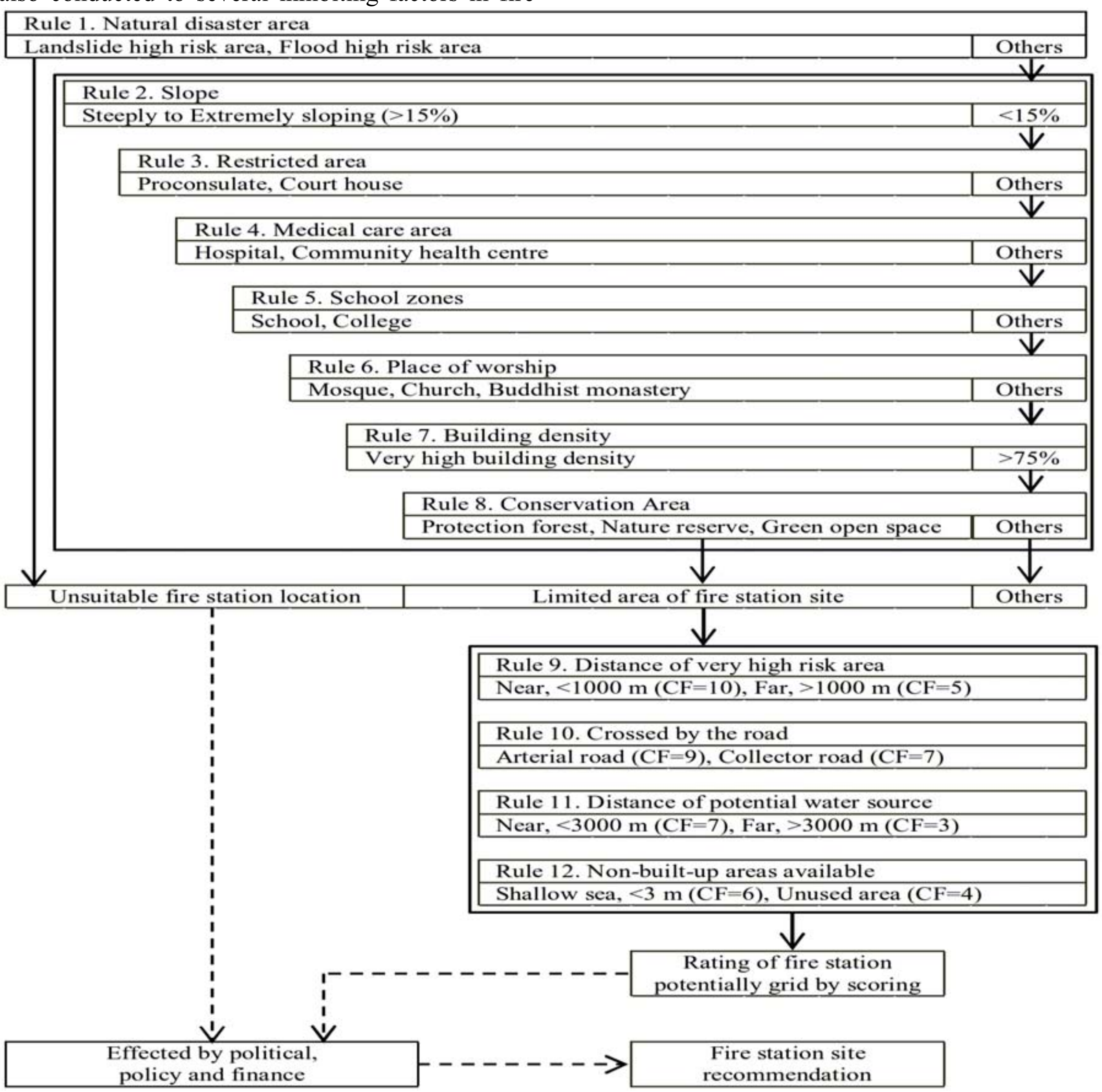

Figure 8: Chart Of Rules System For Fire Station Location In Kendari City

The analysis of fire station location based on expert system approach by using GIS Grid resulted in forty-nine chosen locations, i.e. (1) Suitable I, consists of grid no. 1268 and 1337, (2) Suitable II, amounting to 33 grids, (3) Suitable III, amounting to 14 grids. Out of these 49 grids, the others are unsuitable areas to set the location of the fire station.

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Table 2: Chosen Grid For Fire Station Allocation Suitability In Kendari City

No.	Suitability	Grid Number	Values
1.	Suitable I	1268, 1337	37-40
2.	Suitable II	1033, 1034, 1037,1042, 1043, 1044, 1110, 1115, 1118, 1123, 1183, 1198, 1267, 1269, 1335, 1396, 1496, 1501, 1552, 1553, 1609, 1807, 1808, 1812, 1967, 1968, 2040, 2041, 2202, 2277, 2460, 2559, 3507	33-36
3.	Suitable III	1167, 1178, 1201, 1237, 1343, 1345, 1450, 1451, 1752, 1834, 1985, 1986, 3328, 3496	29-32
4.	Unsuitable	Out of these 49 grids	<29

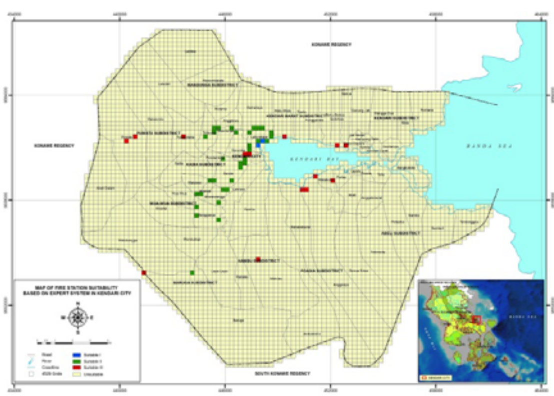

Figure 9: Map Of Fire Station Allocation Based On Expert System Model In Kendari City

4. CONCLUSIONS

The research result studied in Kendari City through Expert System Approach, based on GIS Grid shows that:

1. The fire station allocation should be appropriately close to the high risk of the fire area, located on the arterial road and near with potential water resource to extinguish the fire.
2. The response time service of fire extinguishing (from chosen fire station) toward high risk of fire area should be 4-5 minutes since fire alert.
3. The Expert System approach as a model for urban fire hazard assessment can be showed by selecting one or more of the fire station allocation available alternatives based on existing data.

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