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# Appraisal of Flood Prone Area Management Using Artificial Intelligence Methods in Jakarta Basin, Indonesia

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**Abstract:** Jakarta often experiences floods every rainy season. Some major floods that crippled human activities have occurred in 2002, 2007, 2013, and 2020. The factors affecting the floods are the lowland basin and land subsidence of Jakarta. The analysis used in this study is geographic information systems (GIS) tools with artificial intelligence (AI) methods to produce flood distribution models. Also, hydrogeochemical analysis is conducted to determine seawater intrusion and its correlation with land subsidence that causes floods in Jakarta. The AI methods show that the Genetic Algorithm Rule-set Production, GARP (AUC-ROC = 0.90) has a greater value than the Quick Unbiased Statistical Tree, QUEST (AUC-ROC = 0,79). The results show that GARP is the best method to produce the model distribution of flood hazard points which has been dominating in Northern Jakarta. The correlation between the results of the flood distribution model and the seawater intrusion shows that the condition of land subsidence rate in Jakarta is very massive. The output of this research serves as the basis for determining a better spatial plan for Jakarta in the future.

**Key words:** GIS, artificial intelligence, Jakarta, flood prone area, seawater intrusion.

## Introduction

Floods occur during rainy season creating standing water, especially in the river basins. This puddle arises due to an increase in the volume of water flowing above the ground, either due to high rainfall or river water overflows that enter residential areas (Yusya et al., 2019). Jakarta is one of the metropolitan cities where floods often occur. In the last 20 years, there have been major floods, namely 2002, 2007, 2013, and 2015. In 2020, a massive flood was caused by very high rainfall, also influenced by the city's geographical location (Indonesia Meteorological, Climatological, and Geophysical Agency, 2020; Vroost, 2015). Also, the flood disaster in Jakarta is related to Jakarta's landform which is formed from fluvial, fluvial coastal, and coastal processes (Bemmelen, 1970; Verstappen, 2000). The characteristics of this landform are identified from the fluvial-coastal rock and volcanic-sedimentary rocks. This compilation material is evidence that floods have occurred in the past. This flood-prone area needs to be mapped using a method that produces a fast and precise prediction of flood points using AI.

In addition, the phenomenon of land subsidence that occurs in Jakarta increases the factors causing flood disasters (Abidin et al., 2011). Land subsidence in Jakarta was first spotted in 1926. The evidence of land subsidence is based on repeated equalisation

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measurements carried out in the northern part of Jakarta (Bott et al., 2021). According to the Local Mining Agency, during the 1982–1997 period, land subsidence ranging from 20 to 200 cm was seen in several places in Jakarta. It has been reported over the years that some places have experienced different decreases (Abidin et al., 2011; Murdohardono & Sudarsono, 1998). The allegation of seawater intrusion causes further study of locations suspected of being contaminated by seawater intrusion based on hydrogeochemical analysis and its relation to land subsidence that causes floods.

Based on these environmental problems, an effort is needed to reduce disaster risk by considering the factors that cause floods and water quality in areas in Jakarta. Some predictive maps using GIS techniques are necessary to make a spatial plan. Spatial data analysis was carried out using GIS based on these factors (Stockwell, 1999), but using GIS techniques takes a long time to prepare and process various existing data. Therefore, a new method was needed to make a predictive map using the AI method. The AI methods used in this research are Genetic Algorithm Rule-set Production (GARP) and Quick Unbiased Statistical Tree (QUEST) (Darabi et al., 2019).

Both methods have been used in a flood risk mapping of Sari City, Iran conducted in 2018 (Darabi et al., 2018). Based on this research, the author made a flood risk map in Jakarta to determine the distribution of areas at risk of floods. The objectives of this study are (1) mapping flood hazards based on flood-causing factors such as input data to be approached by AI to produce predictive maps of the flood distribution points in Jakarta, (2) determining the presence of seawater intrusion caused by land subsidence in Jakarta based on water samples carried out by hydrogeochemical analysis, (3) explaining the relationship between seawater intrusion from hydrogeochemical analysis and flood point prediction maps using AI.

## Experiment Section

### Study Areas

Jakarta (5º 19 “12” - 6º 23 “54” S, 106º 22 “42” - 106º 58 “18” E) the capital and largest city of Indonesia was chosen as the study area (Figure 1). Jakarta is located on the north coast of the northwestern part of Java Island. Its area is 661.52 km², which holds a population above 10 million people (Jakarta Statistical Center Agency, 2018).

A total of 13 major rivers (Angke, Grogol, Baru Barat, Baru Timur, Jatikramat, Krukut, Buaran, Mookervaart, Cakung, Pesanggrahan, Ciliwung, Sunter, Cipinang) passes through the city. In addition, there are two flood canals, namely West Flood Canal (Cengkareng drainage system) and East Flood Canal (flowing from East Jakarta to North Jakarta). Most of the rivers in Jakarta are seasonal rivers, which flow heavily during the rainy season, while during the dry season, the flowing water is low. The water level in each river is above the dangerous level during the rainy season, while in the

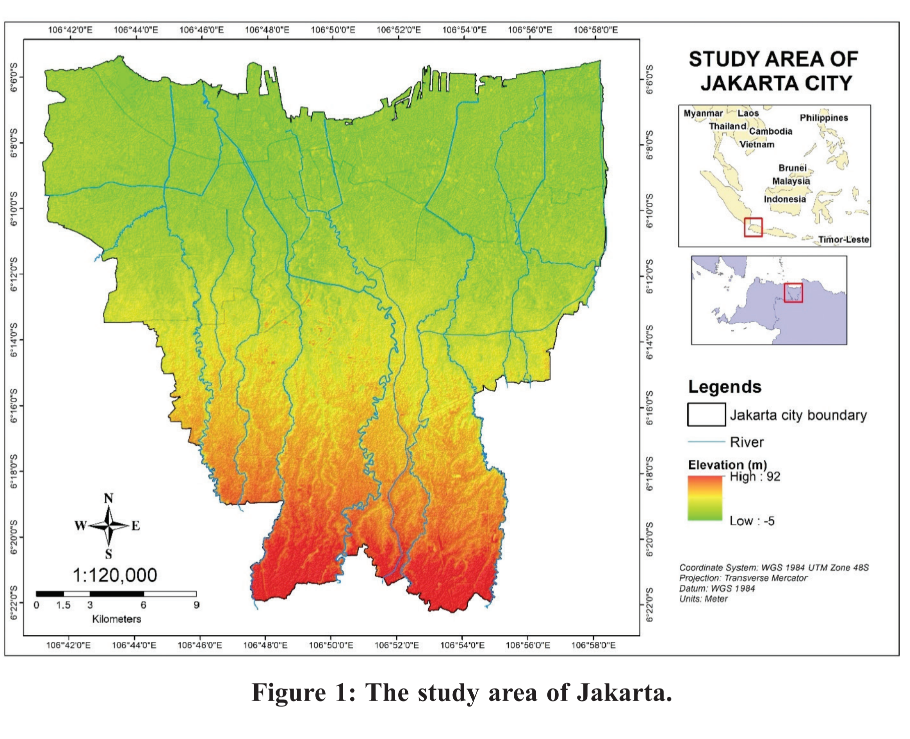



**Figure 1: The study area of Jakarta.**

dry season, the groundwater level is below (Alex et al., 2012). The rivers flowing through Jakarta form a parallel flow pattern, which develops from the previous form of a dendritic river. The river flow density index in Jakarta is 0.60 km/km$^2$, which is a fairly high-density index, indicating that Jakarta has fairly soft and wet rocks (Luo et al., 2019). Ciliwung River is the largest river in Jakarta located in the middle of the city. Land use in Jakarta has been high in residential and office buildings giving rise to high economic activities. Jakarta has hot and dry temperatures or a tropical climate (average temperature 27 °C) with a peak rainy season in January and February, with an average rainfall of 350 millimeters in a day (Marfai et al., 2009). This high-intensity rainfall in January and February has been the reason behind major floods of 2002, 2007, and 2008 (Aldrian, 2009).

## Materials and Methods

### Factors of Flood Hazard

The data used in this study are several factors that can cause floods in urban areas based on the previous research in Sari city, Iran (Darabi et al., 2018). The factors that cause flooding are:

*Rainfall*: Daily rainfall data were obtained from Indonesia Meteorological, Climatological, and Geophysical Agency (BMKG). The rainfall data were obtained from three observation stations in Jakarta: Tanjung Priok Station, Kemayoran Station, and Bintaro Station.

*Land use*: Land use data were obtained from Landsat 8 OLI USGS satellite imagery. Then, the classification of land use was divided into six groups: Built-up land (including residential buildings, commercial, and industrial buildings), water body (river, lake, and pond), vegetation (parks and trees), rice fields, cloud cover, and cloud shadow.

*Ground water depth*: Several studies have explained that groundwater depth data is a factor that influences the initial storage capacity of a basin (Fernandez & Lutz, 2010). The groundwater depth data used in this study were obtained from Jakarta Groundwater Conservation Agency (BKAT). The Groundwater data were obtained from four observation stations in Jakarta, such as Gambir Station, Cilincing Station, Ciracas Station, and Joglo Station.

*Distance to the main river*: It is the distance of 13 main rivers in Jakarta that can cause a flood along the river to the maximum distance. This data was obtained from Indonesia Geospatial Agency (BIG).

*Distance to the channel*: It is the distance of a small river from the 13 main rivers that can cause a flood along the river to the maximum distance. This data was obtained from Indonesia Geospatial Agency (BIG).

*Elevation*: A national digital elevation model (DEMNAS) was obtained from Indonesia Geospatial Agency (BIG). This digital elevation model (DEM) has a spatial resolution of 0.27 arc seconds.

*Slope*: A lowlands have a gentle slope that characterizes a flood in that area. The slope map was extracted from the DEM of the study area using ArcGIS 10.7.1 and divided into five classes based on Van Zuidam (1985). This digital elevation model (DEM) has a spatial resolution of 0.27 arc seconds.

### Flood Distribution Map

A flood distribution map was prepared based on historical flood data obtained from the Jakarta Disaster Management Agency (BPBD Jakarta). In this geographical area, flooding occurs during the rainy season (December-February). Figure 2 shows the distribution point of the floods that occurred in 2015. Figure 3 shows the point of distribution of floods that occurred in January 2020. The distribution of floods in 2015 and January 2020 was chosen because they have similarities to the floods area that occurred by the high rainfall factor.

### Seawater Intrusion Map

Seawater intrusion maps are made based on hydrogeochemical analysis of water samples. Water samples were taken from 13 main rivers in Jakarta. Water samples were collected from 15 sample points, as shown in Figure 4. Then, the samples were analysed using hydrogeochemical analysis to determine the value of the TDS content using a water test kit. In addition, 38 samples of river water were measured for the chemical ion content of $Cl^-$ in the laboratory analysis for a better analysis result.

Two methods were used in this research, such as AI with GIS analysis and hydrogeochemical analysis. The research flow chart is shown in Figure 5.

## Results and Discussions

### Flood Distribution Pattern Analysis Using GARP and QUEST Models (AI Method)

The results of the analysis using GIS produce several

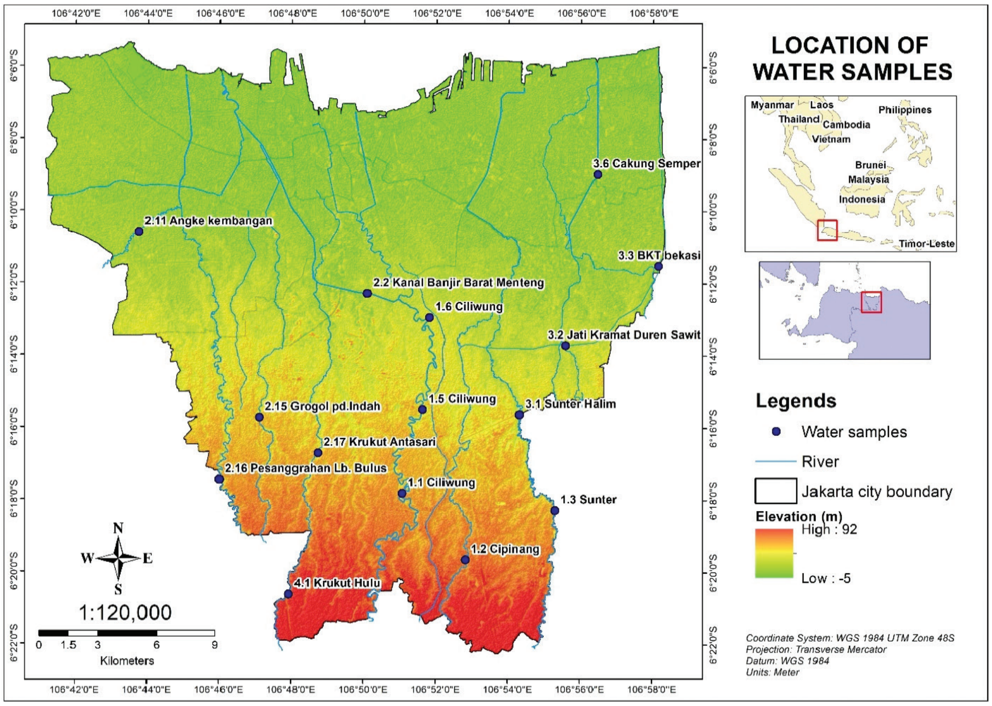



**Figure 2: Map of water sampling locations.**

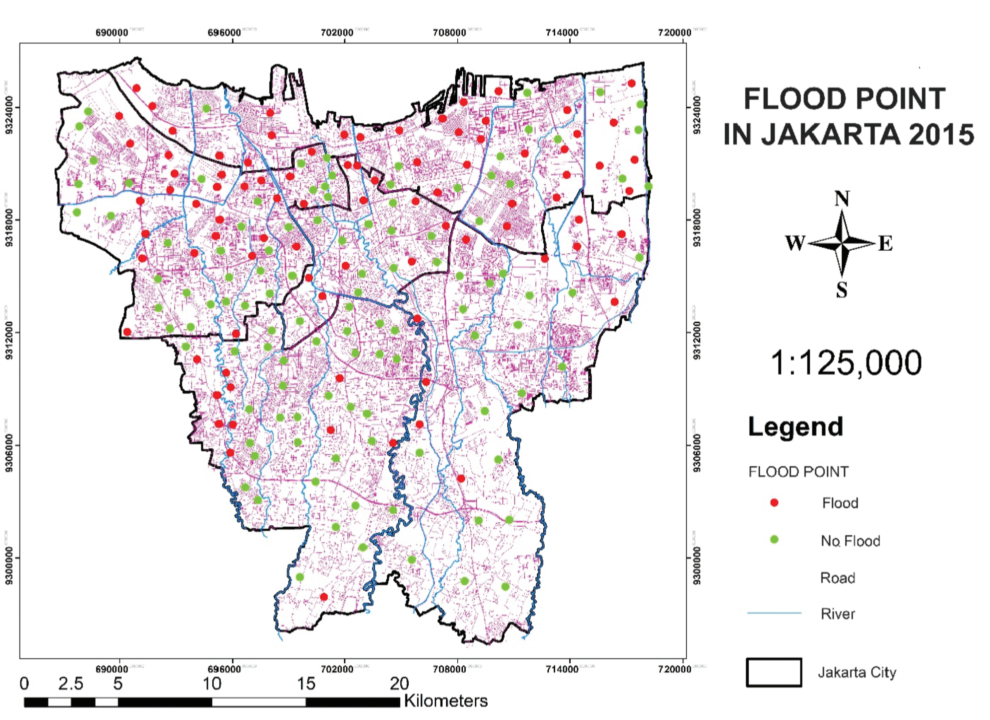



**Figure 3: Flood impact map of Jakarta in 2015.**

maps of rainfall data, groundwater depth, distance to the main river, distance to the channel, land use, elevation, slope, as shown in Figure 6 (a-g). This data was used as input data using the overlay method in the GARP and QUEST models (Moghaddam et al., 2020). The 2015 Jakarta flood data is used as split data for 80% training and 20% validation. Then, it is validated with the January 2020 flood data.

The GARP model, which is a type of AI with a genetic algorithm mechanism, emphasises the right

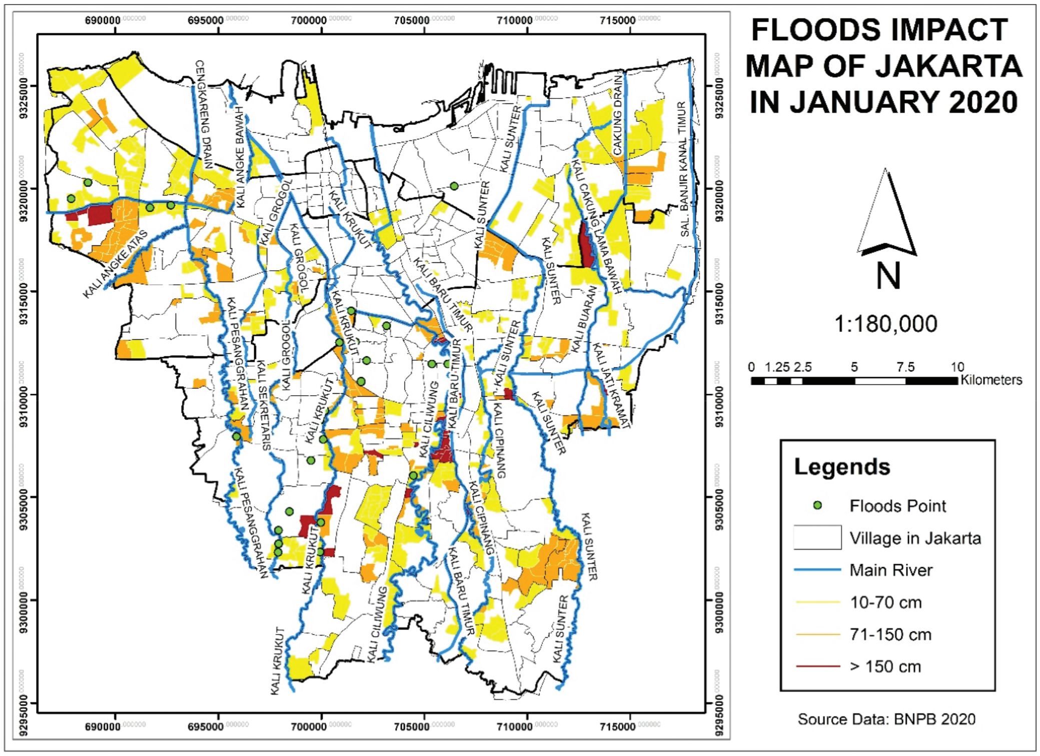



**Figure 4: Flood impact map of Jakarta in January 2020.**

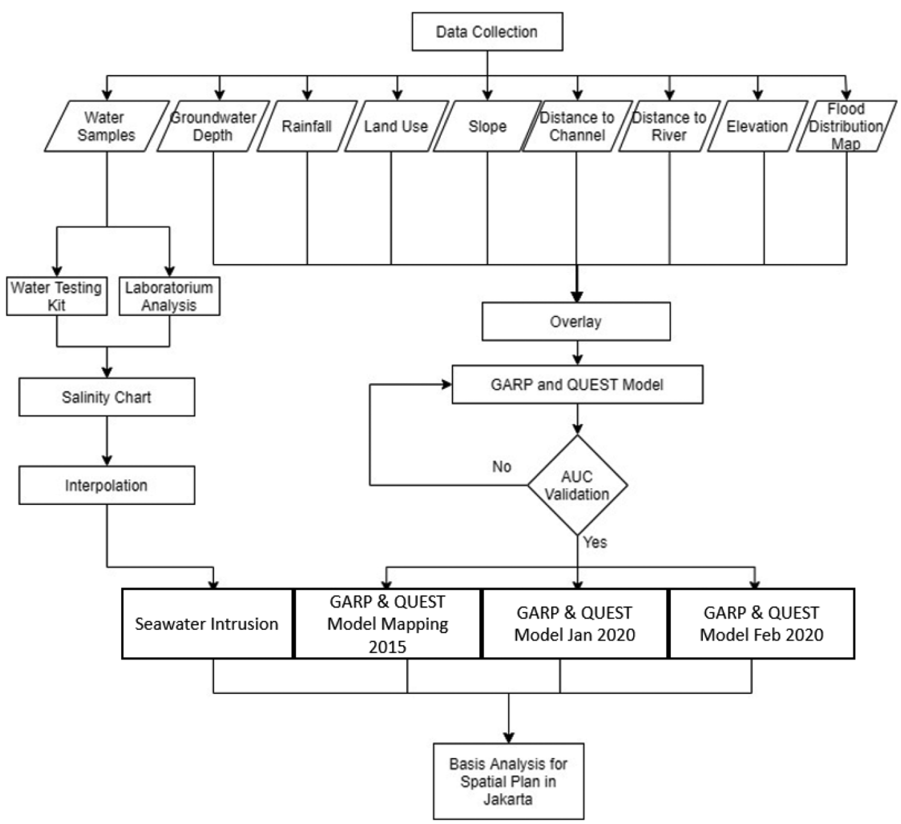
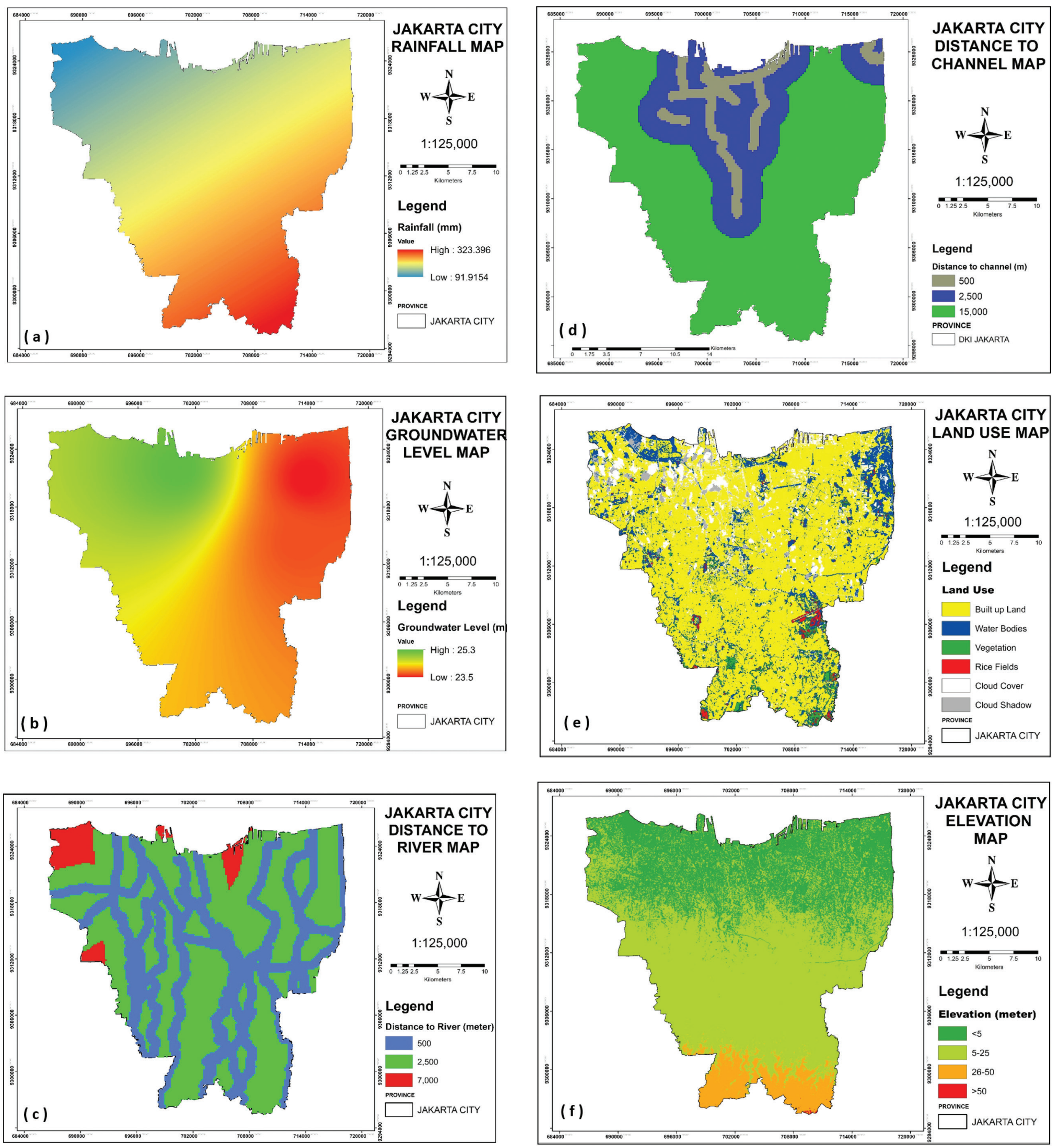



**Figure 5: Research flow chart.**

pattern based on target data in a short time. Meanwhile, the QUEST is a type of AI-based on a statistical tree mechanism that produces more precise results (Darabi et al., 2018). This analysis begins with conducting input data training (rainfall data, groundwater depth, main river distance, and distance of tributaries, land use, elevation, and slope) in 2015. This produces correlation values obtained using the AUC-ROC curve. For the GARP model, the AUC-ROC training data and validation data values are 0.91 and 0.87, respectively,

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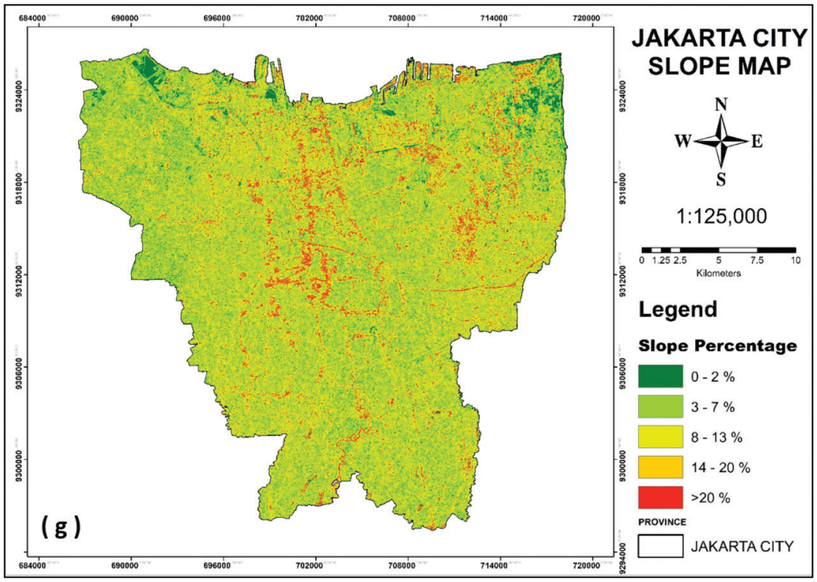


**Figure 6: (a) Rainfall, (b) groundwater level, (c) distance to river, (d) distance to channel (e) land use, (f) elevation and (g) slope.**

as shown in Figure 7 (a-b). Meanwhile, for the QUEST model, AUC-ROC training data and validation data values are 0.88 and 0.83, respectively, as shown in Figure 7(c-d). The area under the ROC curve (ranging from 0 to 1) shows a higher value indicating better model performance (Ngoc-Thach et al., 2018). By using the GARP model highest value can be obtained, thereby proving it to be the best model. Also, AUC-ROC data show agreement between trained models and reality. However, the prediction ability could not be described without the validation step (Bui et al., 2016).

Furthermore, the two models were then validated using target data, namely flood distribution data in January 2020. This validation was used to avoid the overfitting and underfitting data (Falah, 2019). The validation results showed that the AUC-ROC values for the GARP and QUEST models were 0.90 and 0.79, as shown in Figure 7(e-f). The prediction results of the 2015 flood distribution with the GARP model are in Figure 8(a), the 2015 QUEST model flooding distribution is in Figure 8(b), January 2020 flood distribution with the GARP model and the QUEST model are in Figure 8(c-d). February 2020 flood distribution, using the GARP and QUEST model, as a result of the prediction map are shown in Figure 8(e-f). Figure 8(a-f) shows that the validation results of the GARP model in 2015 (AUC-ROC = 0.87) and the January 2020 GARP model (AUC-ROC = 0.90) were higher than the QUEST model in 2015 (AUC-ROC = 0.83) and the January 2020 QUEST model (AUC-ROC = 0.79). These results indicate that the GARP model is better in determining the prediction of flood distribution compared to the QUEST model. Hence, the flood distribution prediction map using the GARP model is preferable for future research of floods in Jakarta.

The GARP model of flood distribution map in Figure 8a shows that the flood points represented by red are concentrated in the northern region of the study area. Meanwhile, the areas that do not produce flood points are represented by white and they are concentrated in the southern region of the study area. The result of flood points is 43 points. The January 2020 flood distribution map using the GARP model in Figure 8b shows that the flood points represented by red are located in the northeast, northwest, and middle of the study area. The areas that do not produce flood points (white) are concentrated in the southern region. The result of flood points is 55 points. On February 2020, the flood distribution map using the GARP model in Figure 8c shows that the flood points represented by red are located in the northeast, southwest, and south of the study area. The white area is concentrated in the southern region. The result is 67 flood points generated in the area.

The QUEST model of the 2015 flood distribution map in Figure 8d shows that the flood points represented by red are concentrated in the northern region of the study area. Meanwhile, the areas that do not produce flood points represented by white are concentrated in the southern region. The result of flood points is 35 points.

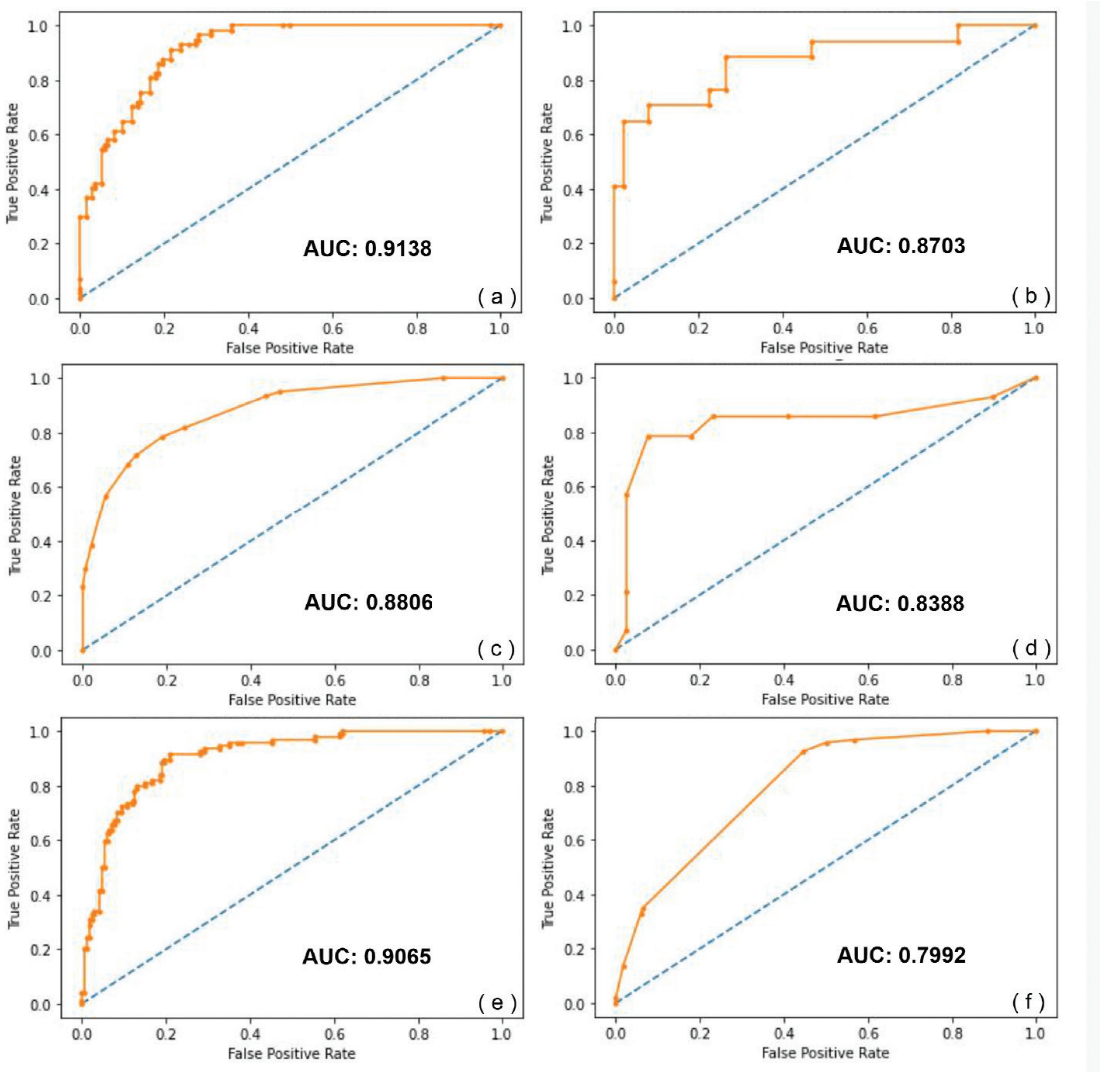


**Figure 7: (a) AUC-ROC training data 2015 GARP, (b) AUC-ROC validating 2015 GARP, (c) AUC-ROC training data 2015 QUEST, (d) AUC-ROC validating 2015 QUEST, (e) AUC-ROC validating 2020 GARP, (f) AUC-ROC validating 2020 QUEST.**

The flood points generated by the QUEST model appear to be less than those produced by the GARP model. On the flood distribution map for January 2020, the QUEST model in Figure 8e shows that the flood points are represented by red, which is located in the northeast and middle of the study area. the areas that do not produce flood points represented by white are concentrated in the southern and western regions of the study area. The result of flood points is 34 points. The flood points generated by the QUEST model appear to be less than those produced by the GARP model. The February 2020 flood distribution map the GARP model given in Figure 8f shows that the flood points represented by red are located in the northeast, southwest, and southern areas of the study area. While the areas that do not produce flood points represented by white are concentrated in the southern region of the study area. The result of flood points is 31 points. The flood points generated by the QUEST model appear to be less than those produced by the GARP model. However, the results demonstrated that the GARP model had higher performance accuracy than the QUEST model because of the AUC-ROC value and the number of detected flooded points (Darabi et al., 2018).

**Seawater Intrusion Map Using Hydrogeochemical and AI Method**

The results of the hydrogeochemical analysis between the TDS and $Cl^{-}$ values are shown in Figure 9 and Table 1. Plotting TDS vs chloride content, there is one of fifteen sample points which is the brackish water type indicated by sample point 3.6. The other sample points were still in the freshwater category. The sample points are mostly located in the south of the central area of Jakarta. Sample point 3.6 is in the northern area of Jakarta, which is directly bordered by the Java Sea. It is concluded that the northern area of Jakarta is a seawater intrusion zone based on the value of TDS and Cl content and the proximity to the sea area. The northern area of Jakarta, especially Cakung Semper, shows low elevation, medium rainfall, high groundwater level, and near water bodies. Seawater intrusion arises

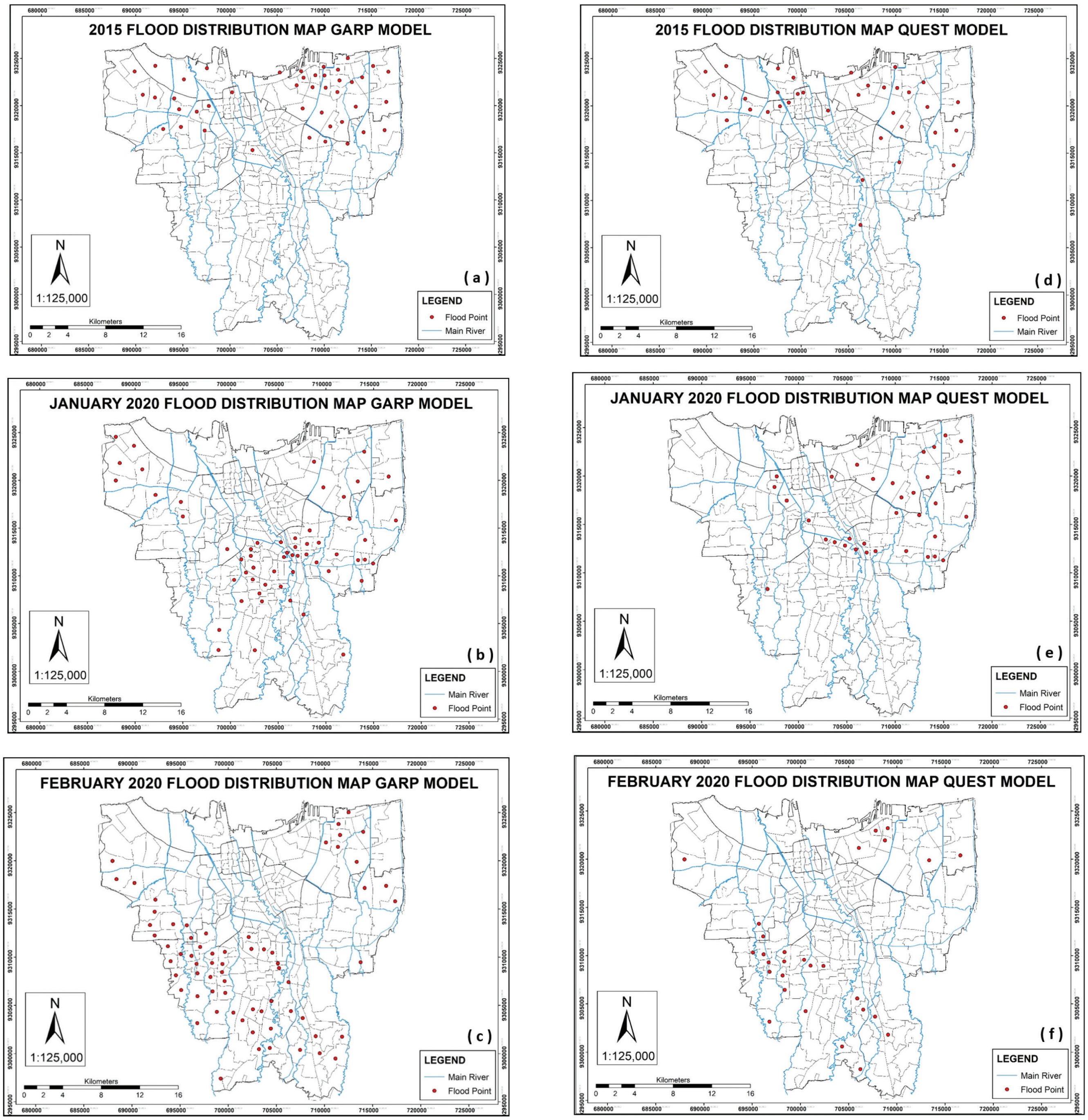


**Figure 8: (a) 2015 flood distribution map GARP, (b) 2015 flood distribution map QUEST, (c) January 2020 flood distribution map GARP, (d) January 2020 flood distribution map QUEST, (e) February 2020 flood distribution map GARP and (f) February 2020 flood distribution map QUEST.**

**Table 1: TDS and Cl content values**

| *Sample* | *1.1* | *1.2* | *1.3* | *1.5* | *1.6* | *2.2* | *2.11* | *2.15* | *2.16* | *2.17* | *3.1* | *3.2* | *3.3* | *3.6* | *4.1* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cl (mg/L)** | 13 | 60 | 30 | 20 | 20 | 20 | 30 | 40 | 20 | 30 | 60 | 50 | 60 | 320 | 20 |
| **TDS (mg/L)** | 117 | 402 | 220 | 129 | 136 | 175 | 293 | 284 | 166 | 176 | 724 | 743 | 857 | 1790 | 134 |

from groundwater pumping in some coastal aquifers (Jasechko et al., 2020).

The results obtained after observing the seawater intrusion map with the flood distribution map produced using the AI method show that there is a correlation regarding the area that is suspected of being seawater intrusion with the resulting flood distribution. The seawater intrusion map shows the alleged intrusion of seawater in the northern area of Jakarta. Figure 10 shows similarities in the areas affected by flooding as the result of the AI method, most of which are in the northern area of Jakarta, as shown in Figure 8 a-c. This shows evidence of land subsidence which is indicated by seawater intrusion causing flooding in the city of Jakarta. According to Abidin et al. (2011), land subsidence is one of the factors causing flooding in Jakarta, because of which, water passing through the 13 rivers of Jakarta, which is a basin area, is trapped for a long time and results in flooding. One of the characteristics of land subsidence is the seawater intrusion which was formed as the result of massive groundwater extraction being carried out in Jakarta. This groundwater extraction is carried out on a large scale to meet the amount of water consumption required by residents in Jakarta. Further research is needed to determine the effect of massive groundwater extraction in the area of multi-story buildings. In addition, this research can be a good basis for determining a good spatial plan in Jakarta for the future so that flood disasters can be reduced and controlled properly.

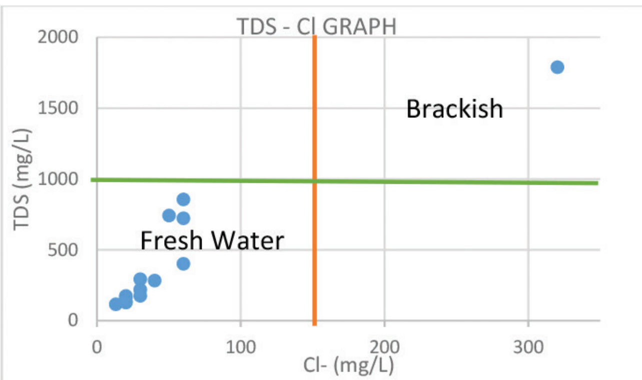


**Figure 9: Water salinity graph based on TDS and Cl values.**

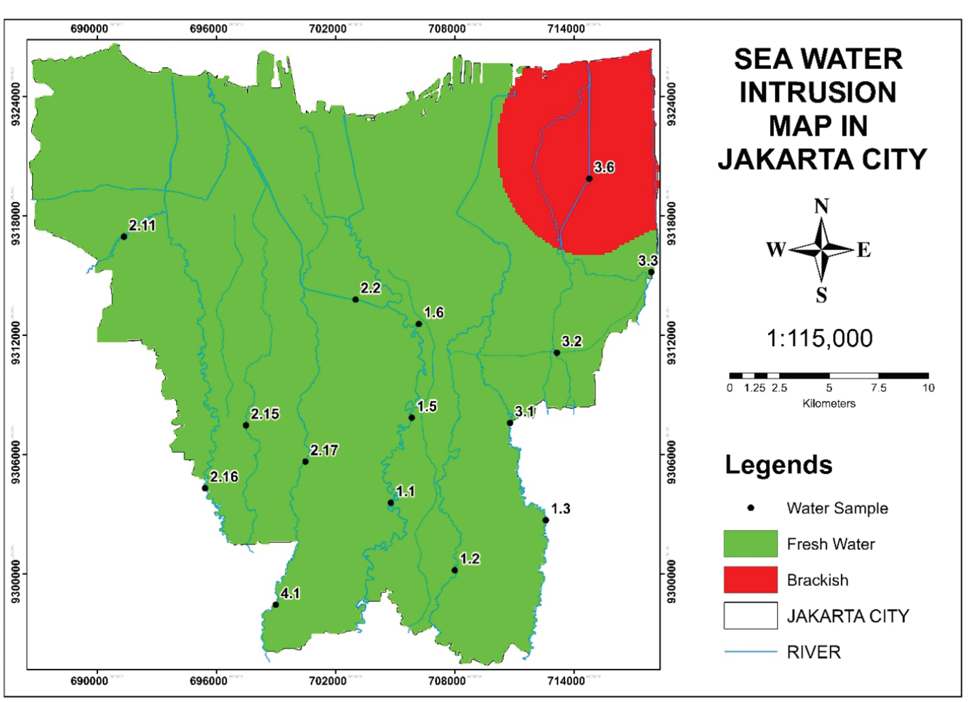


**Figure 10: Seawater intrusion map.**

## Conclusion

In this study, GARP and QUEST models supported by GIS-AI analysis were used to predict the distribution point of floods and to determine the water content of 13 rivers polluted by seawater intrusion. The results showed that the GARP model had a better value than the QUEST model in predicting the flood distribution map of Jakarta. The integration of the hydrogeochemical analysis with the flood distribution map from the AI model shows a linkage of factors caused by land subsidence in Jakarta due to the enormous increase in economic development. These results can be used as planning material in developing a better spatial planning strategy for Jakarta in the future. Based on this research, water resource management and regional support must be carried out more precisely to prevent the spread of areas affected by seawater intrusion, especially Northern Jakarta.

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## References

Abidin, H.Z., Andreas, H., Gumilar, I., Gamal, M., Fukuda, Y. and T. Deguchi (2011). Land subsidence of Jakarta (Indonesia) and its relation with urban development. *Natural Hazards,* **59:** 1753.

Aldrian, E. (2008). Dominant factors of jakartas three largest floods. *J. Hidrosfir Indonesia*, **33:** 105-112.

Alex, H.N., Linlin, G., Xiaojing, L., Hasanuddin, Z.A., Heri, A. and Z. Kui (2012). Mapping land subsidence in Jakarta, Indonesia using persistent scatterer interferometry (PSI) technique with ALOS PALSAR. *International Journal of Applied Earth Observation and Geoinformation*, **18:** 232-242.

Bemmelen, R.V. (1970). The geology of Indonesia. *General Geology of Indonesia and Adjacent Archipelagoes, Government Printing, The Hague 1949*, 1a.

Bott, M.L., Schone, T., Illigner, J., Haghighi, M.H., Gisevius, K. and B. Braun (2021). Land subsidence in Jakarta and Semarang Bay – The relationship between physical processes, risk perception, and household adaptation. *Ocean & Coastal Management,* **211:** 105775.

Darabi, H., Choubin, B., Rahmati, O., Haghighi, A.T., Pradhan, B. and B. Klove (2018). Urban flood risk mapping using the GARP and QUEST models: A comparative study of machine learning techniques. *Journal of Hydrology*, **569**: 142-154.

Falah, F. (2019). Spatial Modeling in GIS and R for Earth and Environmental Sciences. Artificial Neural Networks for Flood Susceptibility Mapping in Data-Scarce Urban Areas, pp. 323-336.

Fernandez, D.S. and MA. Lutz (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. *Eng. Geol*., **111(1-4):** 90-98.

Jasechko, S., Perrone, D., Seybold. H., Fan, Y. and J.W. Kirchner (2021). Widespread potential loss of streamflow into underlying aquifers across the USA. *Nature,* **591(7850):** 391-395.

Luo, P., Kang, S., Apip, Z.M., Lyu, J., Siti, A., Mishra, B., Ram, K.R. and N. Daniel (2019). Water quality trend assessment in Jakarta: A rapidly growing Asian megacity. *PLOS ONE,* **14(7):** e0219009.

Marfai, M.A., Yulianto, F., Hizabron, D.R., Ward, P. and J. Aerts (2009). Preliminary Assessment Modeling the Effects of Climate Change on Potential Coastal Flood Damage in Jakarta, VU University Amsterdam and Gadjah Mada University Yogyakarta, 2009.

Moghaddam, D.D., Rahmati, O., Haghizadeh, A. and Z. Kalantari (2020). A Modeling comparison of groundwater potential mapping in a mountain bedrock aquifer: QUEST, GARP, and RF Models. *Water*, **12(3)**: 679.

Murdohardono, D. and U. Sudarsono (1998). Land subsidence monitoring system in Jakarta. *In:* Proceedings of the symposium on Japan– Indonesia IDNDR project: Volcanology, tectonics, flood and sediment hazards, pp. 243-256.

Ngoc-Thach, N., Ngo, D.B.T., Xuan-Canh, P., Hong-Thi, N., Thi, B.H., NhatDuc, H. and T.B. Dieu (2018). Spatial pattern assessment of tropical forest fire danger at Thuan Chau area (Vietnam) using GIS-based advanced machine learning algorithms: A comparative study. *Ecological Informatics,* **46:** 74-85.

Stockwell, D. (1999). The GARP modeling system: Problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science*, **13(2):** 143-158.

Verstappen, H.Th. (2000). Outline of the Geomorphology of Indonesia: A Case Study on Tropical Geomorphology of a Techtogene Region. *ITC Publication*, 79.

Vroost, R.V. (2015). Applying the risk society thesis within the context of flood risk and poverty in Jakarta, Indonesia. *Health, Risk & Society,* **17(3-4):** 246-262.

Yusya, R.R, Septyandi, M.R. and T.L. Indra (2019). Flood risk mapping of Jakarta using genetic algorithm rule set production (GARP) and quick unbiased efficient statistical tree (QUEST) methods. *IOP Conference Series Materials, Science and Engineering,* pp. 875.

Zuidam, V. (1983). Guide to Geomorphologic-Aerial Photographic Interpretation and Mapping. International Institute for Geo-Information Science and Earth Observation, ITC: Enschede The Netherlands.