Identification of the constraints of physical properties on fluid flow rate (as a preliminary study for analysis of changes in subsurface conditions in the KEK Mandalika Lombok)

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Abstract. The KEK Mandalika area, the southern coast of Lombok Island, is an area that is growing up in the tourism sector. The main need for tourist areas is the availability of clean water. The problem that occurs in coastal areas is seawater intrusion. The seawater intrusion can cause the changes in subsurface conditions, especially in groundwater. These changes have an impact on changes in subsurface physical properties, which can be detected by geophysical measurements and modeling based on geoelectric and gravity data. In monitoring the changes of subsurface conditions, it is necessary to observe the constraints based on the value of conductivity, density, viscosity, and fluid flow rate so that physical modeling can be carried out. The method used was an experiment with 11 mixed solutions of groundwater and seawater with different concentrations. The results show that the salinity, conductivity and density have a proportional relationship with viscosity. The higher the viscosity, the lower the groundwater flow rate, and vice versa. Based on these results, the value of the constraints for each variable is obtained, which is conductivity (1.930-38) mS; density (0.995-1.021) kgm⁻³; salinity (1.06-25.1) ppt; viscosity (0.835-0.876) x10⁻³ kgm⁻¹s⁻¹; fluid flow rate (1292-1388) ms⁻¹.

1. Introduction

Groundwater is a resource needed in life [1]. The problem of water availability is closely related to population growth, seasonal changes, land-use change, geological structure, and excessive groundwater extraction [2]. The KEK (Creative Economy Zone) Mandalika Lombok is a developing area in the tourism sector [3]. Geologically, the KEK Mandalika area is a coastal area with alluvial soils [4]. Alluvial deposits are the result of the secondary deposition so that the compactness between rocks is weak that allows the entry of other substances (pollutants) [5]. In coastal areas, seawater is one of the primary pollutants. Also, seawater is the potential groundwater pollution in coastal areas [6]. The entry of seawater into groundwater is known as a seawater intrusion.

Mixing groundwater with seawater has a result in changing the fluid properties [7]. The groundwater changes are based on thermodynamic properties and fluid flow movements. Viscosity is a fluid-physical property that interprets the thickness of a substance [8]. This property affects the mass transfer system or heat transfer significantly. Density and viscosity are essential for physical properties in the movement and flow of fluid [9]. Viscosity also affects flow rate [10]. The flow rate will be different due to the difference in viscosity. The relationship between viscosity, density, and flow velocity is formulated in Stokes’ Law [11].
The entry of pollutants can result in subsurface changes [12]. Several geophysical methods can be applied in identifying subsurface [13]. The presence of seawater pollutants can cause the density of the subsurface to increase, which is followed by changes in the earth's gravity anomaly [14]. The geophysical method that utilizes the rock density value of the subsurface medium is the gravity method [15]. Apart from the density, one of the factors that have a sharp contrast with the presence of seawater pollutants is the resistivity value. This circumstance happens because of the increase in chloride ion content and salinity that is the result of changes in resistivity or electrical conductivity [16]. Geophysical methods that utilize the resistivity properties of rocks are geoelectric methods [17].

Changes in the physical properties of the fluid that occurs below the subsurface need to be monitored regularly. The changes can be accurately identified if the characteristics of the research area are known. One of the attributes that can be used is the constraint condition. It is necessary to conduct a trial using samples taken directly from the research area in determining the constraint condition for providing accurate regional characteristic information. The constraint conditions of several parameters can be used as a reference in analysis, interpretation, and prediction at the next stage to overcome environmental problems in coastal areas, especially the KEK Mandalika Lombok area.

2. Method
This research was conducted on August 2020 at the KEK Mandalika, Lombok, NTB. A sampling of seawater, groundwater, and sand is carried out directly. Seawater samples were taken at a distance of ± 100 from the shoreline at coordinates 08° 53 '43.26 "LS, 116° 16' 59.50" BT. Groundwater samples were taken at a distance of ± 750 meters from the shoreline at coordinates 08° 53 '14.22 "LS, 116° 16' 59.92 "BT. Meanwhile, beach sand is taken from the shoreline at coordinates 08° 53 '40.35 "LS, 116° 16' 59.63 "BT. The location at each sampling point is plotted on the GPS. The location can be seen in Figure 1.

![Figure 1. Map Location of Sample (modified from Google Maps)](image)

This research is a laboratory-based quantitative descriptive study. The materials used in this study were the distilled water, meanwhile the primary data from the test samples. Sand samples were tested based on their density. Groundwater and seawater samples were made into 11 solutions with different ratio of concentrations mixture of seawater and groundwater: 1: 0, 0.9: 0.1, 0.8: 0.2, 0.7: 0.3, 0.6:0.4, 0.5:0.5, 0.4:0.6, 0.3:0.7, 0.2:0.8, 0.1:0.9, 0:1. The sample made is then tested in the laboratory with several test parameters, including:

2.1 Conductivity, Salinity, and Temperature Testing
Conductivity, salinity, and temperature testing using the EC meter (Electrical Conductance) 9000 Model that is submerged into the sample. Conductivity and salinity laboratory test results then made a simple linear regression graph to see how closely the relationship between the two variables. Simple linear regression involves only two variables are X and Y. The regression line equation and the coefficient of determination can be formulated as follows [18]:

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Where Y is the dependent variable, X is the independent variable, a is the intercept, and b is the regression coefficient or slope.

The coefficient of determination (R²) is part of the total diversity of the dependent variable (Y), then Y can be explained by the diversity of the independent variables (X). This coefficient is calculated by squaring the correlation coefficient. The interpretation of the coefficient of determination is provided in Table 1 [19].

### Table 1. Interpretation of The Value of Determination Coefficient (R²)

| No. | R²      | Interpretation         |
|-----|---------|------------------------|
| 1   | 0.00 - 0.25 | No relationship/ weak relationship |
| 2   | 0.26 - 0.50 | Medium relationship    |
| 3   | 0.51 - 0.75 | Strong relationship    |
| 4   | 0.76 - 1.00 | Very strong relationship/perfect |

#### 2.2 Density Testing

Density testing was carried out on two types of materials, namely 11 water samples and sand samples. Analysis of the data from the water, and sand density test results used equation 1 [20].

$$\rho = \frac{m}{V}$$  

(2)

Where m is mass (kg) and V is volume (ml).

Data from 11 water samples from the analysis of equation (2) are compared to the density values based on the density variation table for seawater in a function of temperature and salinity that can be seen in table 2 [21].

### Table 2. Density Variations of Seawater in Temperature and Salinity Functions [21]

| Salinity ppm | T (°C) | 10000 | 20000 | 30000 | 40000 | 50000 | 60000 | 70000 |
|--------------|--------|-------|-------|-------|-------|-------|-------|-------|
| 10           | 1008   | 1015  | 1023  | 1031  | 1038  | 1046  | 1054  |
| 15           | 1007   | 1014  | 1022  | 1030  | 1037  | 1045  | 1053  |
| 20           | 1006   | 1013  | 1021  | 1028  | 1036  | 1044  | 1051  |
| 25           | 1004   | 1012  | 1019  | 1027  | 1034  | 1042  | 1050  |
| 30           | 1003   | 1010  | 1018  | 1025  | 1033  | 1040  | 1048  |
| 35           | 1001   | 1008  | 1016  | 1023  | 1031  | 1038  | 1046  |
| 40           | 999    | 1007  | 1014  | 1021  | 1029  | 1036  | 1044  |
| 45           | 997    | 1004  | 1012  | 1019  | 1027  | 1034  | 1042  |
| 50           | 995    | 1002  | 1010  | 1017  | 1024  | 1032  | 1039  |
| 55           | 993    | 999.9 | 1007  | 1015  | 1022  | 1029  | 1037  |
| 60           | 990    | 997.5 | 1005  | 1012  | 1020  | 1027  | 1034  |
| 65           | 988    | 994.9 | 1002  | 1010  | 1017  | 1024  | 1032  |
| 70           | 985    | 992.2 | 999.5 | 1007  | 1014  | 1022  | 1029  |
| 75           | 982    | 989.3 | 996.6 | 1004  | 1011  | 1019  | 1026  |
| 80           | 979    | 986.3 | 993.7 | 1001  | 1008  | 1016  | 1023  |
| 85           | 976    | 983.2 | 990.6 | 997.9 | 1005  | 1013  | 1020  |
| 90           | 973    | 980   | 987.4 | 994.7 | 1002  | 1010  | 1017  |
| 95           | 969    | 976.7 | 984   | 991.4 | 998.8 | 1006  | 1014  |
| 100          | 966    | 973.2 | 980.6 | 988   | 995.4 | 1003  | 1010  |
| 105          | 962    | 969.6 | 977   | 984.4 | 991.9 | 999.3 | 1007  |
| 110          | 958    | 965.9 | 973.3 | 980.8 | 988.3 | 995.7 | 1003  |

#### 2.3 Viscosity Testing

The Viscosity testing used the correlation equation between viscosity and temperature and salinity based on table 3.
Table 3. Variation of Seawater Viscosity in Temperature and Salinity Function [21]

| Salinity ppm | T (°C) 10000 | 20000 | 30000 | 40000 | 50000 | 60000 | 70000 |
|-------------|-------------|-------|-------|-------|-------|-------|-------|
| 10          | 1.31        | 1.338 | 1.365 | 1.395 | 1.428 | 1.463 | 1.5   |
| 15          | 1.15        | 1.175 | 1.199 | 1.226 | 1.255 | 1.286 | 1.319 |
| 20          | 1.02        | 1.04  | 1.062 | 1.086 | 1.112 | 1.14  | 1.169 |
| 25          | 0.91        | 0.928 | 0.948 | 0.969 | 0.993 | 1.018 | 1.044 |
| 30          | 0.82        | 0.833 | 0.851 | 0.871 | 0.892 | 0.915 | 0.939 |
| 35          | 0.74        | 0.753 | 0.77  | 0.788 | 0.807 | 0.827 | 0.849 |
| 40          | 0.67        | 0.684 | 0.7   | 0.716 | 0.734 | 0.753 | 0.772 |
| 45          | 0.61        | 0.625 | 0.639 | 0.655 | 0.671 | 0.688 | 0.706 |
| 50          | 0.56        | 0.573 | 0.587 | 0.601 | 0.616 | 0.632 | 0.649 |
| 55          | 0.52        | 0.529 | 0.541 | 0.555 | 0.569 | 0.584 | 0.599 |
| 60          | 0.48        | 0.489 | 0.501 | 0.514 | 0.527 | 0.541 | 0.555 |
| 65          | 0.44        | 0.455 | 0.466 | 0.478 | 0.49  | 0.503 | 0.516 |
| 70          | 0.41        | 0.424 | 0.435 | 0.446 | 0.457 | 0.469 | 0.482 |
| 75          | 0.39        | 0.397 | 0.407 | 0.417 | 0.428 | 0.439 | 0.451 |
| 80          | 0.36        | 0.372 | 0.382 | 0.392 | 0.402 | 0.413 | 0.424 |
| 85          | 0.34        | 0.35  | 0.359 | 0.369 | 0.379 | 0.389 | 0.399 |
| 90          | 0.32        | 0.33  | 0.339 | 0.348 | 0.357 | 0.367 | 0.377 |
| 95          | 0.3         | 0.313 | 0.321 | 0.329 | 0.338 | 0.347 | 0.357 |
| 100         | 0.29        | 0.296 | 0.304 | 0.312 | 0.321 | 0.33  | 0.338 |
| 105         | 0.27        | 0.282 | 0.289 | 0.297 | 0.305 | 0.313 | 0.322 |
| 110         | 0.26        | 0.268 | 0.275 | 0.283 | 0.291 | 0.298 | 0.307 |

2.4 Flow Rate Test
The data obtained from the analysis of several physical parameters testing in the laboratory are then performed flow rate analysis to determine the fluid flow rate. The flow rate analysis equation uses the Stokes’ equation [22] as follows:

\[ v = \frac{2r^2g}{9\eta} \left( (\rho_p - \rho_f) \right) \]  

(3)

Where \( \eta \) is the fluid viscosity coefficient (Pa.s), \( r \) is the sphere/filter radius (m), \( g \) is the acceleration due to gravity (ms\(^{-2}\)), \( \rho_p \) is the density of sand (kgm\(^{-3}\)), and \( \rho_f \) is the density of the fluid (kgm\(^{-3}\)), assuming that it is a fluid moved.

3. Results and Discussion
The results of laboratory tests on 11 water samples with different concentrations are shown in table 4. The results consist of various parameters include viscosity, salinity, density, temperature, and conductivity, as well as the flow velocity parameters in groundwater in the KEK Mandalika. The temperature of the sample tested is constant at 28.1 °C.
Table 4. The Results of Laboratory Testing on 11 Water Samples

| Number of sample | Concentrations         | Mass (Kg) | Conductivity (mS) | Density (kgm\(^{-3}\))\(^*\) | Density (kgm\(^{-3}\))\(^**\) | Temperature (°C) | Salinity (ppt) | Viscosity (*10\(^{-3}\) kgm\(^{-1}\)s\(^{-1}\)) | Sand Density (kgm\(^{-3}\)) | Fluid radius (m) | Velocity of Flow Rate (ms\(^{-1}\)) |
|------------------|------------------------|-----------|------------------|-----------------------------|-----------------------------|------------------|--------------|--------------------------------|-------------------|-----------------|-----------------------------------|
| 1                | 100% Seawater          | 25.51407  | 38               | 1020.5628                   | 101.627                     | 28.1             | 25.1          | 0.876                                   | 2086.648           | 0.698057815 | 1291.469509                                    |
| 2                | 90% Seawater + 10% Groundwater | 25.41783  | 35.1             | 1016.7132                   | 1013.063                    | 28.1             | 23            | 0.872                                   | 2086.648           | 0.698057815 | 1302.078529                                    |
| 3                | 80% Seawater + 20% Groundwater | 25.32044  | 32               | 1012.8176                   | 1011.353                    | 28.1             | 20.7          | 0.868                                   | 2086.648           | 0.698057815 | 1312.841566                                    |
| 4                | 70% Seawater + 30% Groundwater | 25.31012  | 28.4             | 1012.4048                   | 1009.793                    | 28.1             | 18            | 0.864                                   | 2086.648           | 0.698057815 | 1319.426553                                    |
| 5                | 60% Seawater + 40% Groundwater | 25.24975  | 25.4             | 1009.99                     | 1008.16                     | 28.1             | 16.4          | 0.86                                    | 2086.648           | 0.698057815 | 1328.543166                                    |
| 6                | 50% Seawater + 50% Groundwater | 25.17221  | 22               | 1006.8884                   | 1006.382                    | 28.1             | 14            | 0.856                                   | 2086.648           | 0.698057815 | 1338.596418                                    |
| 7                | 40% Seawater + 60% Groundwater | 25.10485  | 18               | 1004.194                    | 1004.753                    | 28.1             | 11.8          | 0.852                                   | 2086.648           | 0.698057815 | 1348.236884                                    |
| 8                | 30% Seawater + 70% Groundwater | 25.08284  | 13.85            | 1003.3136                   | 1002.284                    | 28.1             | 8.46          | 0.847                                   | 2086.648           | 0.698057815 | 1357.298823                                    |
| 9                | 20% Seawater + 80% Groundwater | 24.99087  | 10.13            | 999.6348                    | 1000.521                    | 28.1             | 6.07          | 0.843                                   | 2086.648           | 0.698057815 | 1368.370152                                    |
| 10               | 10% Seawater + 90% Groundwater | 24.94058  | 6.43             | 997.6232                    | 998.818                     | 28.1             | 3.76          | 0.839                                   | 2086.648           | 0.698057815 | 1377.438312                                    |
| 11               | 100% Groundwater        | 24.86489  | 1.93             | 994.5956                    | 996.83                      | 28.1             | 1.06          | 0.835                                   | 2086.648           | 0.698057815 | 1387.884582                                    |

* Density of the measured solution  
** Density of Solution calculated based on the table
Based on table 4, it can be seen that the high viscosity value can be affected by the increased of salinity, while the increase in water salinity can be caused by an event of seawater intrusion. Based on Figure 2 and Figure 3, it can be seen that the trend of the two charts is the same. Where the salinity and conductivity decreases based on the reduced concentration of seawater in the sample. Based on Table 4, it was found that the salinity values ranged from 1.06-25.1 ppt and the conductivity values ranged from 1.93-38 mS.

![Figure 2. The relationship between Salinity and Sample Concentration](image1)

![Figure 3. The relationship between Conductivity and Sample Concentration](image2)

![Figure 4. Conductivity Simple Linear Regression on Salinity](image3)

Figure 4 shows the relationship between salinity and conductivity. Conductivity is the dependent variable and salinity is the independent variable which is analyzed using simple linear regression analysis. Simple linear regression analysis was performed to measure how much influence salinity had on conductivity.

Based on Figure 4, it can be seen that salinity and conductivity have a positive linear relationship, which means that the greater the salinity value, the greater the value of conductivity with the regression equation obtained is \( Y = 1.4934X + 0.7997 \). Where \( Y \) is conductivity, \( X \) is salinity, and the coefficient of determination \( (R^2) \) of 0.9994 means that salinity has a big effect on conductivity.

If there is intrusion of seawater, there will be an increase in the content of chloride ions which will have an impact on the increase of salinity value followed by an increase in the value of conductivity [16]. In addition, seawater has electrolyte properties compared to the groundwater, so it is able to conduct electricity well. This characteristic is the reference for geophysical measurements. So that to determine subsurface changes based on the value of the conductivity can use the geophysical method, namely the geoelectric resistivity method.
The next parameter is density. Density expresses the size of the mass against the volume of an object. In this study, it is comparing the density value of the measurement results with Table 2. Based on the Figure 5, it can be seen that the density values measured by laboratory tests have a similar graphical tendency, with the average measurement error of the 11 samples is 0.108%. This result proves that the laboratory tests carried out provide usable data.

Based on the results obtained, there is an increase in density with the addition of seawater concentration in the sample. This means that if there is seawater intrusion, there will be an increase in mass which will result in a change of density. Theoretically, the density value of seawater is 1025 $kg/m^3$ and pure groundwater is 1000 $kg/m^3$. While based on Table 4, the density value in this study is (995-1021) $kg/m^3$. The results obtained are close to the existing theory. Its means that, if there is seawater intrusion, the seawater will have a position above groundwater because the density of seawater is greater than the density of groundwater. If this happens to the environment, it will affect the quality and quantity of groundwater in an area. To see changes in subsurface density can be identified by geophysical methods, namely the gravity method.

One of the factors that greatly influence the fluid flow rate is viscosity. Viscosity states the thickness of a fluid. Viscosity produces a velocity gradient. The viscosity value on the graph in Figure 6 is the calculated value based on Table 3, which is due to the limitations of tools that have a measurement value range that can measure very small changes in viscosity values in water. Based on the graph above, it can be seen that the lower the concentration of sea water in groundwater, the smaller the viscosity value. The viscosity values obtained were $(0.835-0.876) \times 10^{-3} \, kg/m^3/s$.

The viscosity value and the density value are very influential in the fluid flow rate. The relationship of these variables is formulated by Stokes' Law. However, this study assumes that the flowing acid is fluid. The results of observations on the flow rate of the solution concentration are shown in Figure 7. Figure 7 shows that the greater the concentration of seawater, the smaller the flow rate. This change is inversely to the viscosity value as shown in Figure 6. Based on this fact it can be concluded that the viscosity of the fluid greatly affects the groundwater flow rate. Changes in groundwater flow rate can
affect water discharge so that the impact on water demand is very significant. Based on the analysis, it was found that the flow rate was 1292-1388 m$^{-1}$. This means that if there is seawater intrusion there will be an increase in salinity, conductivity, density and viscosity which will have an impact on decreasing groundwater flow rate in the study area.

4. Conclusion
Based on the research results, it can be concluded that predicting groundwater flow rate, it can be done by measuring its physical parameters, namely viscosity, density, salinity, temperature, and electrical conductivity. The results show that the salinity, conductivity and density have a proportional relationship with viscosity. The higher the viscosity, the lower the groundwater flow rate, and vice versa. Based on these results, the value of the constraint for each variable is obtained, which is conductivity (1.930-38) mS; density (0.995-1.021) kg m$^{-3}$; salinity (1.06-25.1) ppt; viscosity (0.835-0.876) x10$^{-3}$ kg m$^{-1}$ s$^{-1}$; fluid flow rate (1292-1388) m$^{-1}$.

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