1. Introduction

The people in developing countries often had dependency to groundwater resource and thus it becomes an essential and valuable water resource [1], the number of societies facing water shortages is increasing as the level of the groundwater table decreases as a consequence of excessive usage and the level of pollution of surface and groundwater resources increases due to several anthropogenic activities [2]. For this reason, there have been many studies on water quality in various parts of the world. As a vital source of drinking water and irrigation, groundwater quality should be monitor and protect from the contaminant [3]. Groundwater in the coastal area is commonly susceptible to an environmental problem such as saltwater intrusion [4, 5] and upconing [6]. The salinity of water resources is a significant problem that the world population suffers. It has been studied intensively during the past decades, particularly in coastal aquifers [7]. The complexity and non-linearity of saltwater intrusion in the coastal area become a challenge [8], several reasons could explain the salinity of groundwater such as a consequence of leaching of evaporates in waterlogged areas, weathering of minerals, the movement of saline groundwater to the shallower aquifer as a result of over-pumping [9], change and variation of climate condition and rising of sea-level [10]. At this time, the coastal area facing rapid development. In several areas, the used of coastal land changed into the industrial area, which results in more problems not only for the groundwater but also seawater, especially in the area where the industrial waste has not managed improperly. Those could lead to groundwater quality problems, and even worse, the surrounding residents cannot use the resources in daily activity due to health issues [11].
taminant, the possibility of saltwater intrusion, and the aquifer capability as the primary source of water [13]. In addition, the electrical resistivity tomography (ERT) method could become a supporting data to model the geometry of aquifer [14] and locating contaminant [15]. This method could also detect the pathway of pollution [16] and the boundary of freshwater and saltwater from the difference of electrical current [17].

Groundwater conditions in coastal areas in Indonesia had been affected by the human, land used activity, and groundwork [18]. Seasonal differences affected the discharge volume and nutrient variations of groundwater [19]. The salinity of groundwater occurred in major cities and found to intruded the groundwater wells, both shallow and deep wells [20]. It is occurred not only on the wells that closed to the shoreline [21] but also in further sites [22]. One of the major provinces in Indonesia, Riau, has also faced saltwater intrusion and upconing problems, particularly in the coastal areas and in the islands. The study conducted in Bengkalis island (Fig. 1), located in the Malacca Strait on the east coast of Riau mainland. Initial groundwater monitoring had detected the salty water in freshwater wells as well as in the river [23]. The northern part of the study area occupied by people and there are several beaches for tourism spots, meanwhile in the land in the southern part of the study area occupied by the harbors, and populated residential area.

Stratigraphy condition of the study area (Fig. 1) based on the regional geological map from [24] was composed of Older Superficial Deposit (Qp) and Young Superficial Deposit (Qh). Older Superficial Deposits consist of clays, silts, clayey gravels, vegetation rafts, and Young Superficial Deposit consists of clays, silts, clean gravel, vegetation rafts, peat swamps [25].

2. Methodology

Fieldwork activities consist of measuring the existing wells to obtain several data such as groundwater level, in-situ groundwater quality, and groundwater geochemistry (from water samples). Groundwater well was measured randomly both from shallow (dug) and deep wells across the island. In total, there are 22 dug wells and five bore wells (deep well) located near the coast and in the middle of the study area (Fig. 2). Five bore wells chosen by the availability of well’s information (Table 1) as well as geological information of the well. The connection between dug well and bore well is the similarity of geological conditions surrounding the well.

Well’s depth, electrical conductivity (EC), and total dissolved solids (TDS) were among the in-situ parameters that measured directly in the field. Water samples collected using a plastic bottle sealed with an inner cap, the bottle must be full with water so that no water bubbles inside, and preserved in the container to keep the water temperature in stable condition. The samples delivered to the Water Analytic Laboratory of National Nuclear Energy Agency (BATAN) to analyze the major ion such as Na, K, Ca, Mg, Cl, HCO3, and SO4. Stiff and piper diagram then plotted to determine the groundwater type.

| Well ID | Depth (m) | Average depth of water table (m) | Distance from the coast (m) |
|---------|-----------|--------------------------------|---------------------------|
| BKS 1   | 3.3       | 2.1                            | 2,250                     |
| BKS 2   | 1.2       | 0.8                            | 740                       |
| BKS 3   | 2.1       | 0.8                            | 1,430                     |
| BKS 4   | 2.9       | 0.9                            | 1,720                     |
| BKS 5   | 4.4       | 4.2                            | 2,990                     |
| BKS 6   | 2.7       | 2.2                            | 8,860                     |
| BKS 7   | 3.8       | 1.0                            | 1,390                     |
| BKS 8   | 1.9       | 0.4                            | 1,760                     |
| BKS 9   | 3.2       | 1.1                            | 1,150                     |
| BKS 10  | 3.0       | 3.0                            | 1,110                     |
| BKS 11  | 1.6       | 1.2                            | 1,210                     |
| BKS 12  | 2.6       | 0.1                            | 1,360                     |
| BKS 13  | 2.5       | 0.6                            | 3,180                     |
| BKS 14  | 3.0       | 1.1                            | 1,300                     |
| BKS 15  | 1.4       | 1.2                            | 4,670                     |
| BKS 16  | 3.5       | 1.5                            | 6,820                     |
| BKS 17  | 2.5       | 1.9                            | 5,160                     |
| BKS 18  | 1.9       | 0.4                            | 1,280                     |
| BKS 19  | 1.9       | 0.4                            | 1,430                     |
| BKS 20  | 1.2       | 0.5                            | 2,820                     |
| BKS 21  | 3.0       | 1.0                            | 5,090                     |
| BKS 22  | 2.0       | 1.0                            | 5,460                     |
| BKS B1  | 115       | 60                             | 2,650                     |
| BKS B2  | 60        | 40                             | 1,580                     |
| BKS B3  | 54        | 40                             | 2,740                     |
| BKS B4  | 57        | 35                             | 2,940                     |
| BKS B5  | 81        | 60                             | 2,300                     |

Fig. 1. Geological map of Bengkalis Island and well location map in the study area.
Saltwater intrusion analysis conducted using several methods commonly used in the previous study [26] to identified groundwater status:

a. The enrichment of Ca calculated using the formula from [27] and [28] based on the ratio of Ca and Mg concentration (in mg/L). High ratios (> 1) could be the indication of saltwater intrusion [27].

\[
\text{Ca Enrichment} = \frac{\text{Ca}}{\text{Mg}}
\]  

(1)

b. [29] proposed the Simpson Ratio based on the Cl, HCO₃, and CO₃ concentration (in mg/L).

\[
\text{Simpson Ratio} = \frac{\text{Cl}}{\text{HCO}_3 + \text{CO}_3}
\]  

(2)

The ratio describes the contamination level and divided into five classes as shown in Table 2.

| Ratio     | Quality                  |
|-----------|--------------------------|
| < 0.5     | Good quality             |
| 0.5-1.3   | Slightly contaminated    |
| 1.3-2.8   | Moderately contaminated   |
| 2.8-6.6   | Injuriously contaminated  |
| 6.6-15.5  | Highly contaminated       |

c. The ratio of sodium chloride (in mg/L) based on [27] to shows the impact on the groundwater. Saltwater intrusion impact would be shown by ratios less than 0.86, while anthropogenic sources of contamination would be demonstrated by ratio > 1. For the ratio value between 0.86 – 1, the mean value (0.93) become the limit to determine the contamination process. If it is less than 0.93, the contaminant source seems to be SWI. Meanwhile, if it is more than 0.93, the anthropogenic activity would be the cause of contamination.

\[
\text{Sodium Chloride Ratio} = \frac{\text{Na}}{\text{Cl}}
\]  

(3)

d. Calculating Base Exchange Indices (BEX) proposed by [30] to distinguish if an aquifer in the salinization or freshening process.

\[
\text{BEX} = \frac{\text{Na} + \text{K} + \text{Mg} - 1.0716\text{Cl}}{\text{in meq/L}}
\]  

(4)

Positive BEX indicates the freshening process, negative BEX indicates the salinization process, and zero value indicates no base exchange.

Stable Isotopes ($\delta^2$H, $\delta^18$O) were analyzed using LGR Laser DLT-100. The result of stable isotopes plotted into the graph to identify the origin of the water. Interaction of groundwater-seawater traced using $\delta^2$H and $\delta^18$O isotope analysis and hydrochemical methods. Both isotopes used as a marker in identifying the source of groundwater in the aquifer, the possibility could be coming from rain, deeper or shallower groundwater, seawater, fossil water, or magmatic water ([21]; [31]). The isotope analysis in Riau province studied by [32] was the first to define the Local Meteoric Water Line (LMWL) found that the reference value for LMWL in this area is $\delta^2$H = 7.6 $\delta^18$O + 10.5 ($r^2 = 0.921$).

3. Result and Discussion

Hydrogeochemical analysis shows several major ions that have a significant role in the groundwater. The dominant ions found were sodium, chloride, bicarbonate, and sulfate. Carbonate analyzed, but the reagent shows no reaction indicated the absence of that ion. Table 3 shows the value for each major ion in groundwater samples.

The sequence of major ion could define the primary ions in a groundwater sample [33]. From groundwater samples that located near the coast, the cation sequences found as Na > Mg > K > Ca, Na > Ca > Mg > K, Na > Ca > K > Mg and Mg > Na > K > Ca, while Na > Ca > Mg > K, Na > Mg > Ca > K and Na > Mg > K > Ca sequences found in the samples located in the middle of the island. In general, the most dominant cation sequence is Na > Mg > K > Ca found in 11 samples.

The anion sequences found as Cl > HCO₃ > SO₄, Cl > SO₄ > HCO₃, HCO₃ > Cl > SO₄, dan SO₄ > Cl > HCO₃ for water samples that located close to the coast, while Cl > SO₄ > HCO₃ and HCO₃ > Cl > SO₄ sequences found in the samples located in the middle of island. Cl > HCO₃ > SO₄ is the most dominant anion sequence in the study area, found in 10 samples.

3.1. Groundwater Facies

The concentration of each major ion plotted into Stiff diagram (Fig. 2) and Piper diagram (Fig. 3) to identify the type and facies of groundwater in the study area.
Fig. 3. Piper plot of shallow groundwater and deep groundwater samples.

Stiff diagram shows the water type based on dominant cation and anion in groundwater samples. Several water types had found, such as sodium chloride (NaCl), sodium bicarbonate (NaHCO₃), magnesium chloride (MgCl), magnesium sodium bicarbonate (Mg, Na-K, HCO₃) and sodium sulfate (NaSO₄). Sodium seems to be the governing cation to determined water type from groundwater samples, and for anion, chloride became dominant ions that are ruling in the determination of water types. Fig. 3 shows the distribution of dug wells groundwater samples and the distribution of deep wells groundwater samples using Piper diagram to identify the facies and evolution of groundwater in the study area.

There are several groundwater facies determined from the cation triangle (left side), such as magnesium type, sodium or potassium type, and no dominant type (shown by red triangle). Sodium or potassium type was the dominant type of groundwater from the cation plot. From the anion triangle (right side), there are sulfate type groundwater, chloride type, bicarbonate type, and no dominant type.
3.2. Saltwater Intrusion Analysis

Several analyses had done to determine the status of groundwater toward the saltwater intrusion phenomenon (Table 4).

Table 4. Saltwater Intrusion Analysis for Each Groundwater Well

| WELL ID | Ca Enrichment | Ca Remark | Simpson Ratio | Cation Remark | Sodium Chloride Ratio | Anion Remark | BEX | Remark | Overall Remark |
|---------|---------------|-----------|---------------|---------------|----------------------|--------------|-----|--------|----------------|
| BKS 1   | 0.122         | Normal    | 1.199         | Slightly      | 0.880                | SWI          | 13.861 | Freshening | More Freshening Process |
| BKS 2   | 13.963        | SWI       | 3.632         | Injuriously   | 0.861                | SWI          | 1.740  | Freshening | More SWI Process |
| BKS 3   | 0.569         | Normal    | 4.125         | Injuriously   | 0.491                | SWI          | -0.251 | Salinization | More SWI Process |
| BKS 4   | 0.676         | Normal    | 6.326         | Injuriously   | 0.400                | SWI          | -1.365 | Salinization | More SWI Process |
| BKS 5   | 0.044         | Normal    | 0.916         | Slightly      | 0.983                | Anthropogenic | 20.524 | Freshening | More Freshening Process |
| BKS 6   | 0.273         | Normal    | 0.796         | Slightly      | 1.138                | Anthropogenic | 20.884 | Freshening | More Freshening Process |
| BKS 7   | 0.050         | Normal    | 0.523         | Slightly      | 1.540                | Anthropogenic | 13.886 | Freshening | More Freshening Process |
| BKS 8   | 1.137         | SWI       | 62.538        | Highly        | 0.560                | SWI          | -4.641 | Salinization | More SWI Process |
| BKS 9   | 4.516         | SWI       | 0.204         | Good          | 1.313                | Anthropogenic | 1.126  | Freshening | More Freshening Process |
| BKS 10  | 7.260         | SWI       | 0.000         | Good          | 0.580                | SWI          | 0.028  | Freshening | More SWI Process |
| BKS 11  | 0.716         | Normal    | 0.000         | Slightly      | 1.073                | Anthropogenic | 1.084  | Freshening | More Freshening Process |
| BKS 12  | 1.659         | Normal    | 0.000         | Good          | 1.313                | Anthropogenic | 1.153  | Freshening | More Freshening Process |
| BKS 13  | 0.044         | Normal    | 0.636         | Slightly      | 1.084                | Anthropogenic | 10.404 | Freshening | More Freshening Process |
| BKS 14  | 1.424         | SWI       | 0.000         | Good          | 0.756                | SWI          | 1.369  | Freshening | More SWI Process |
| BKS 15  | 1.000         | SWI       | 0.000         | Good          | 0.726                | SWI          | 0.061  | Freshening | More SWI Process |
| BKS 16  | 0.481         | Normal    | 0.000         | Good          | 0.633                | SWI          | 0.077  | Freshening | More Freshening Process |
| BKS 17  | 0.035         | Normal    | 0.394         | Good          | 1.225                | Anthropogenic | 6.433  | Freshening | More Freshening Process |
| BKS 18  | 0.838         | Normal    | 0.000         | Good          | 0.404                | SWI          | -1.145 | Salinization | More Freshening Process |
| BKS 19  | 1.560         | SWI       | 0.000         | Slightly      | 0.462                | SWI          | -13.280 | Salinization | More SWI Process |
| BKS 20  | 0.290         | Normal    | 0.000         | Slightly      | 0.548                | SWI          | 1.700  | Freshening | More Freshening Process |
| BKS 21  | 0.151         | Normal    | 0.973         | Slightly      | 0.748                | SWI          | 2.440  | Freshening | More Freshening Process |
| BKS 22  | 0.280         | Normal    | 0.833         | Good          | 0.921                | SWI          | 7.147  | Freshening | More Freshening Process |
| BKS B1  | 0.036         | Normal    | 0.596         | Slightly      | 1.240                | Anthropogenic | 10.744 | Freshening | More Freshening Process |
| BKS B2  | 0.402         | Normal    | 0.456         | Good          | 0.940                | Anthropogenic | 2.100  | Freshening | More Freshening Process |
| BKS B3  | 0.380         | Normal    | 5.150         | Injuriously   | 0.446                | SWI          | -1.038 | Salinization | More SWI Process |
| BKS B4  | 0.359         | Normal    | 5.218         | Injuriously   | 0.456                | SWI          | -1.066 | Salinization | More SWI Process |
| BKS B5  | 0.172         | Normal    | 1.866         | Moderately    | 0.617                | SWI          | 1.910  | Freshening | More Freshening Process |

3.2.1. The enrichment of Ca

36.4% of shallow groundwater samples found to be affected by the saltwater intrusion having a ratio greater than 1. It comes from BKS 2, BKS 8, BKS 9, BKS 10, BKS 12, BKS 14, BKS 15, and BKS 19 station, while the rest of samples indicating normal condition by having a ratio less than 1. Meanwhile, the deep wells sample not yet reporting the saltwater intrusion problem.

3.2.2. Simpson ratio

From the calculation of chloride and bicarbonate ratio, 45.5% of shallow groundwater samples are fall into good condition category, 40.9% are in slightly contaminated, and 13.6% are in injuriously contaminated. Meanwhile, the deep groundwater samples found to be in good condition in BKS B2, slightly contaminated in BKS B1, moderately contaminated in BKS B5, and BKS B3, BKS B4 classified into injuriously contaminated state.

3.2.3. Sodium chloride ratio

NaCl ratio indicating the source of the contaminant in groundwater. 63.6% of shallow groundwater samples contaminated by saltwater intrusion (SWI), while the other 36.4% contaminated by anthropogenic sources. Deep well groundwater samples show saltwater
intrusion contamination in BKS B3, BKS B4 and BKS B5, and anthropogenic contamination in BKS B1, BKS B2.

3.2.4. Base exchange indices (BEX)
Salinization or freshening process in groundwater could identify using BEX value. The positive value indicating the freshening process shown by 77.3% shallow groundwater samples, and the other 22.7% shows the salinization process, which indicating from negative BEX value. BKS B1, BKS B2, BKS B5 shows freshening process in deep water well, while BKS B3 and BKS B4 indicated the salinization process.

3.2.5. Saltwater intrusion zone
The calculation methods show differences based on the result’s similarity and the relationship between the techniques. Even though in several wells indicate the disagreement of the result compares to one method with another, in general, all these four methods are suitable to determine the saltwater intrusion problem in groundwater samples. Saltwater intrusion process found in 36.4% shallow groundwater samples and 40% of deep groundwater samples. The saltwater intrusion zone map (Fig. 4) shows the conditions of aquifer processing in the northern part and the southern part of the study area.

Most of the process was freshening of the aquifer and some indications of contamination from anthropogenic activity. However, several wells found to experience the saltwater intrusion process. The zone of intrusion likely to be upcoming condition. The SWI impacted wells located in the middle of the freshening process, and the cause of this phenomenon could be excessive use of water.

3.3. Isotope Groundwater
Stable isotope δ²H and δ¹⁸O determined from 5 groundwater samples. They then plotted with Global Meteoric Water Line (GMWL) shown by a firm orange line and with Local Meteoric Water Line (LMWL) of Riau Province from [32] demonstrated by dash orange line.

The groundwater samples found to be in line with GMWL and LMWL, the water samples might be originated from the higher elevation or distance source. The more SWI process in the wells (Table 4) indicating the mixing of groundwater and seawater that intruded the wells, and it is an undergoing process. Meanwhile, BKS B4 and BKS B5 shown lighter 2H value compare to the other samples that are indicating the groundwater flown in the deeper part of the aquifer.

4. Conclusions
In conclusion, the result of this research found several water
types in the study area determined from Stiff diagram, such as sodium chloride (NaCl), sodium bicarbonate (NaHCO₃), magnesium chloride (MgCl), magnesium sodium bicarbonate (Mg-Na-KHCO₃) and sodium sulfate (NaSO₄). Also, Piper diagram shows the occurrence of several groundwater facies such as calcium sulfate waters, sodium chloride waters, sodium bicarbonate waters, and calcium bicarbonate waters. The identification of the saltwater intrusion problem using four different calculations shows a similar process in each groundwater well. Most of the groundwater aquifer experienced the fresening process. However, several wells suggested the saltwater intrusion impact and the mode of intrusion likely to be an upcoming process. Isotope groundwater data in some wells give the information of water origin. The groundwater found originated either from the higher elevation or distance source, and there was an indication of deeper groundwater flow in the aquifer as well. The further study of isotope groundwater needs to perform to analyze groundwater-seawater interaction.

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Author Contributions

D.B.E.P (M.Sc) and Y.Y (M.Eng) conceived the study. D.B.E.P (M.Sc), M.S.D.H (Ph.D.), B.Y.C.S.S.A (Ph.D.) and W.Z.W.Y (Ph.D.) designed the research methods. D.B.E.P (M.Sc), W.P.D.H (B.Eng) and Y.Y (Ph.D.) data acquisition, M.S.D.H (Ph.D.), W.Z.W.Y (Ph.D.) and B.D (Ph.D.) provided statistical input; D.B.E.P (M.Sc), W.P.D.H (B.Eng) and B.Y.C.S.S.A (Ph.D.) data analysis, interpretation and wrote the manuscript. W.Z.W.Y (Ph.D.) and B.D (Ph.D.) provided grammatical revision to the manuscript. D.B.E.P (M.Sc) and W.P.D.H (B.Eng) provided manuscript revision.

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