Volume 16
Number 1
JUNE 2024

Journal of
The Indonesian Society of Integrated Chemistry
P-ISSN 2085-1715 & E-ISSN 2621-5543
Published by Jambi University, Chemistry Education Study Program
JISIC

Quantitative Analysis of Mineral in Seawater Concentrate from Pamekasan, Madura Using XRF and ICP-OES Methods

Barmi Hartesi[1,5], **Yoga windu wardhana**[2], **Muhaimin**[3] **Sriwidodo**[2],
***Miski Aghnia* Khairinisa**[4], **Mayang Kusuma Dewi**[1], **Anis Yohana Chaerinisaa**[2]

1. Doctoral Program, Faculty of Pharmacy, Universitas Padjadjaran, Jl. Raya Jatinangor Km 21.5, Sumedang 45363, Indonesia
2. Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmacy, Universitas Padjadjaran, Sumedang 45363, Indonesia
3. Department of Pharmaceutical Biology, Faculty of Pharmacy, Universitas Padjadjaran, Sumedang 45363, Indonesia
4. Department of Pharmacology and Clinical Pharmacy, Faculty of Pharmacy, Universitas Padjadjaran, Sumedang 45363, Indonesia
5. Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmacy, Universitas Jenderal Achmad Yani, Cimahi 40531, Indonesia

---

ABSTRACT

Seawater concentrate from Pamekasan is a product with high mineral content. The mineral content analysis of Pamekasan seawater concentrate was conducted using a comparative test of results from X-Ray Fluorescence Spectrometry (XRF) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). This mineral content testing used a skin moisture device. The essential minerals found in Pamekasan seawater concentrate through analysis are Mg, Cl, K, Ca, Cr, Mn, Cu, and Zn. Statistical analysis results from XRF and ICP-OES on market products showed no significant difference in average results; however, there was a significant difference in average results in the samples. The most recommended method for analyzing seawater mineral concentrate from Pamekasan is ICP-OES due to its wider detection range and lower matrix interference.

Keyword: ICP-OES, Seawater Concentrate, Minerals, XRF.

INFO ARTIKEL

Received: June 15, 2024;
Revised: June 24, 2024;
Accepted: June 28, 2024

* coresponding: anis.yohana.chaerunisaa@unpad.ac.id
DOI: https://doi.org/10.22437/jisic.v16i1.34656

INTRODUCTION

Pamekasan is one of the water-producing regions in Madura, often referred to as the "Water Island" due to being one of the largest water producers in Indonesia. This is attributed to the dense seawater containing high levels of minerals. The harvest of seawater results in a byproduct called seawater concentrate, liquid rich in minerals.

The utilization of mineral concentrate also helps in minimizing marine pollution caused by the disposal of mineral concentrate, which can act as a pollutant to seawater (Sriwidodo, et al). Currently, seawater mineral concentrate is being used in the health sector as a raw material for health supplements due to its rich mineral content. Products such as Concentrated Mineral Drop by Revell Global, Ocean Mineral Topical Facial Serum by Island Brand, and Shea MD Anderson Health Solution (Megawati, 2020) are examples of its applications.

The minerals contained in seawater concentrate can be essential or non-essential. Essential minerals required by the body include Mg, Na, K, Ca, P, Fe, I, Zn, Se, Mn, F, Cr, Cl, and Cu (MenKes RI, 2019). Non-essential minerals, which can be either toxic or non-toxic and not required by the body, include Al, Ag, Co, S, Ba, La, and Ni. Additionally, heavy metals such as As, Hg, Cd, and Pb may also be found (Wani et al., 2015; WHO, 2017; ATSDR, 2023; FDA, 2023).

Heavy metals can originate from natural sources such as rock weathering and volcanic activity, as well as human activities like agriculture, shipping, mining, industrialization, urbanization, and waste disposal (Muhamad et al., 2022). Heavy metals pose a significant problem due to their environmental impact and health risks, including cancer (Erian et al., 2021). Therefore, to assess the quality and potential of Pamekasan Madura seawater concentrate as a nutraceutical, an analysis of its content and comparison with market products is necessary.

This study employs X-Ray Fluorescence Spectrometry (XRF) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) for content analysis. XRF was chosen for its relative ease and cost-effectiveness, as it requires no special sample preparation and can analyze both liquid and solid samples without damaging them (Siti Amirah, 2022). However, XRF has limitations in detecting levels below ppm. On the other hand, ICP-OES was selected for its high sensitivity and low detection limits (Arif Susanti et al., 2021). ICP-OES can measure concentrations as low as 0.1 ppb. However, it requires special sample preparation and has a longer analysis time compared to XRF, resulting in higher costs. Therefore, a comparative test between XRF and ICP-OES analysis results is needed to determine the best method for analyzing Pamekasan Madura seawater concentrate.

METHODS

Equipment

XRF Spectrometer (Rigaku Nex CG), Heavy Metal Digester, ICP-OES (Agilent 700 Series ICP-OES), Filter Paper (Whatman No.41), Glassware (Commonly used PYREX glassware in Print-G and the Central Laboratory of Universitas Padjadjaran).

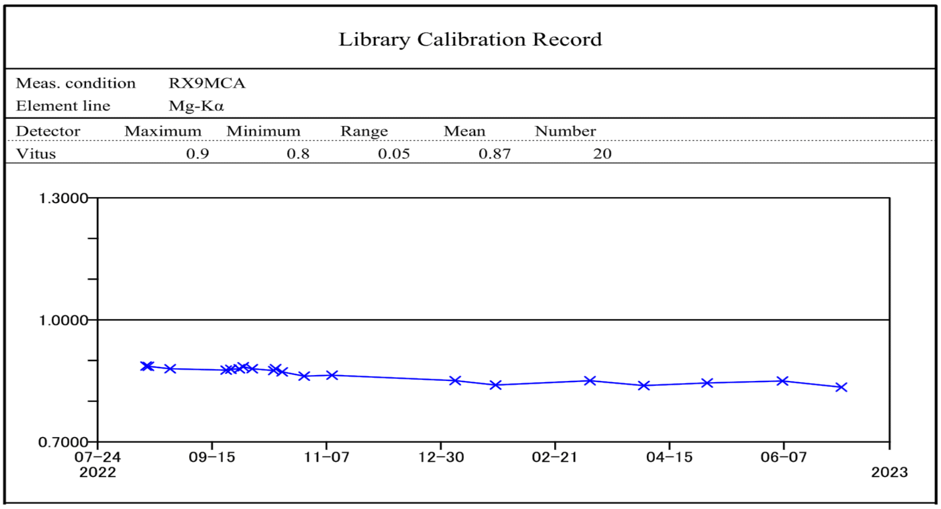
Materials

Seawater Concentrate from Pamekasan, Madura (sample), Commercial Seawater Concentrate Products (For comparison), HNO3 and HCl.

Procedure

1. Preparation of Seawater Concentrate
   Seawater with a density of 3-4° Be is transferred to a holding pool until it reaches a density of 5° Be. It is then channeled through a ditch until it reaches a density of 7° Be, then directed to a water table until it reaches a density of 27° Be. The water is allowed to precipitate until it reaches a density of 32° Be. The supernatant is drained until it reaches a density of 35° Be and is allowed to precipitate further until it reaches a density of 36° Be (Sriwidodo et al., 2020).
2. Sample Filtration
   The sample is filtered using Whatman filter paper no. 41.
3. Mineral Content Analysis with XRF Spectrometer
   After turning on the computer and the instrument, allow the device to warm up for 30 minutes. Set the helium gas flow to 0.66 L/min with a pressure of 10-15 psi. Before sample analysis, calibrate the instrument with the "MCA calibration sample". For liquid sample analysis, place the sample in a sample holder lined with plastic film, cover it, and insert it into the instrument. Choose "FP Analysis" and select "Modify" to choose the elements to be analyzed. Click "Data Processing" and "Result Display" to obtain the analysis results (Purna Pirdaus et al., 2019).
4. Mineral Content Analysis with ICP-OES
   The sample and comparison need to undergo wet digestion first. Place 10 ml of the comparison and seawater concentrate sample into a digestion flask, then add 3 ml of HCl and 1 ml of HNO3. Perform digestion with a heavy metal digester for 15 minutes at 95°C. Allow the sample to cool, then filter using Whatman No. 41 filter paper. Dissolve the digested sample and observe its absorption with ICP-OES to determine the content in the sample and comparison (Suprapto et al., 2016). For ICP-OES analysis, turn on the device and increase the Breaker High Voltage ICP. Activate the autosampler and open the ICP Expert II software. Allow the ICP to purge for 20 minutes. Turn on the water cooler. Ignite the plasma by clicking the plasma ON icon. Click the Torch Align menu and then Torch Scan. Close the instrument window. Create a method, read the standard and sample by clicking the worksheet menu. To print the analysis results, click the file menu and select report setting. To end the use of ICP-OES, exit the ICP Expert II software.

RESULTS AND DISCUSSION



Library Calibration Record

Meas. condition RX9MCA
Element line Mg-Kα

Detector	Maximum	Minimum	Range	Mean	Number
Vitus	0.9	0.8	0.05	0.87	20

Figure 1. XRF Instrument Calibration Results

Table 1. Detection Limit and Quantitation Limit of XRF

Element	Detection Limit (ppm)	Quantitation Limit (ppm)
Mg	2340	7020
Si	414	1240
S	370	1100
Cl	30,5	91,4
K	19,4	58,3
Cr	2,25	6,74
Cu	2,99	8,98
Br	0,903	2,71
Rb	5,79	17,4
Sn	2,78	8,33
Ta	7,27	21,8
Th	3,29	9,88

Table 2. Mineral Concentrations Listed on the Labels of Commercial Seawater Concentrate Products

Element	Amount per Serving (mg/5 ml)	mg/l
Mg	422	84400
Na	90	18000
K	116	23200
Ca	0,2	40
S	36	7200

Table 3. Analysis Results and Total Daily Value (DV) Reaching the Upper Intake Limit for Seawater Concentrate and Commercial Products Using XRF and ICP-OES

Elements	Comparison (mg/l)		Sample (mg/l)		Total Daily Value (DV) of Sample Reaching Upper Intake Limit
	XRF	ICP-OES	XRF	ICP-OES	
Essential Minerals					
Mg	53200	1362,7395 ± 0,8145	75700 ± 1336	1337,2445 ± 1,5095	1-3 years: Same >19 years: Exceeds

Elements	Comparison (mg/l)		Sample (mg/l)		Total Daily Value (DV) of Sample Reaching Upper Intake Limit
	XRF	ICP-OES	XRF	ICP-OES	
					Other ages: No
P	0	*	0	*	-
Cl	160000	*	187000 ± 1319	*	No
K	21500	18488,626 ± 137,197	12000 ± 361	11062,173 ± 3,3445	No
Ca	0	13,3760	74,4 ± 16,9	13,4485 ± 0,0795	No
Cr	2,56	<0,0001	0	<0,0001	No
Mn	0	4,544 ± 0,0205	0	0,262 ± 0,001	No
Fe	0	<0,0001	23,3	<0,0001	No
Cu	7,46	<0,0001	8,005 ± 1,395	<0,0001	No
Zn	0	0,2185 ± 0,004	0	<0,0001	No
Se	0	<0,0001	0	<0,0001	-
Mo	0	<0,0001	0	<0,0001	-
I	0	*	0	*	-
			Mineral toksik		
Al	0	<0,0001	0	<0,0001	-
In	0	*	0	*	-
Tl	0	<0,0001	0	<0,0001	-
As	0	0,0385 ± 0,0235	0	<0,0001	-
Hg	0	<0,0001	0	<0,0001	-
Cd	0	<0,0001	0	<0,0001	-
Pb	0	<0,0001	0	<0,0001	-
			Non-Essential and Non-Toxic Minerals		
Si	1870	*	2170 ± 96	*	-
V	0	*	0	*	-
Co	0	<0,0001	0	<0,0001	-
Ni	0	<0,0001	0	<0,0001	-
Ag	0	0,39 ± 0.083	0	0,0925 ± 0,093	-
Sn	78,6	*	70,7 ± 2,2	*	-
Sb	0	<0,0001	0	<0,0001	-
Ba	0	*	0	*	-
La	0	*	0	*	-
Ce	0	*	0	*	-
U	0	*	0	*	-
S	20700	*	18800 ± 220	*	-
Nb	0	*	0	*	-
Ru	0	*	0	*	-
Rh	0	*	0	*	-
Pd	0	*	0	*	-
Y	0	*	0	*	-
Ti	0	*	0	*	-
Ga	0	<0,0001	0	<0,0001	-
Te	0	<0,0001	0	<0,0001	-
Cs	0	*	0	*	-
Ge	0	*	0	*	-
Br	3010	*	3950 ± 10	*	-
Rb	49,9	*	59,1 ± 3,5	*	-
Pr	0	*	0	*	-
Nd	0	*	0	*	-
Hf	0	*	19,6	*	-
Ta	11,4	*	12,4 ± 2,4	*	-
W	0	*	0	*	-
Ir	0	*	0	*	-

Elements	Comparison (mg/l)		Sample (mg/l)		Total Daily Value (DV) of Sample Reaching Upper Intake Limit
	XRF	ICP-OES	XRF	ICP-OES	
Pt	0	*	0	*	-
Au	0	<0,0001	0	<0,0001	-
Bi	0	0,288 ± 0,128	0	<0,0001	-
Sr	0	<0,0001	0	<0,0001	-

* No standard solution in the laboratory

▨ = Heavy Metals

Table 4. Repeated Measures ANOVA Output for Label, XRF, and ICP-OES

Normality Test	
Standardized Residual for Label	Sig. : 0,514
Standardized Residual for XRF	Sig.: 0,789
Standardized Residual for ICP-OES	Sig. : 0,126
Mauchly's Test of Sphericity	Sig. : 0,003
Pairwise Comparisons	Label and XRF *Mean difference* : 10980 ppm Sig. : 1 Label and ICP-OES *Mean difference* : 29277,295 ppm Sig. : 1 XRF dan ICP-OES *Mean difference* : 18297,295 ppm Sig. : 1
Test of Within-Subjects Effects (Greenhouse-Geisser)	Sig. : 0,390
Elements: Mg, K, and Ca	

Table 5. Comparison Output with Wilcoxon Test

Normality Test	Sig. : 0,001
Ranks	
Negative Ranks	2
Positive Ranks	6
Ties	0
Test Statistics	Sig. : 0,674
Elements: Mg, K, Ca, Mn, Zn, As, Ag, and Bi	

Table 6. Sample Output with Wilcoxon Test

Normality Test	Sig. : 0,001
Ranks	
Negative Ranks	8
Positive Ranks	2
Ties	17
Test Statistics	Nilai signifikansi (Sig.) : 0,013
Elements: Mg, Al, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Sr, Mo, Ag, Sn, Sb, Te, Au, Hg, Tl, Pb, and Bi	

The sample used is seawater concentrate from Pamekasan, Madura, which has a high mineral content and thus has the potential to be further processed into nutraceutical products. The sample will be compared with commercial seawater concentrate products available in the market. The analysis of the seawater concentrate content was conducted using XRF and ICP-OES methods because both methods are capable of simultaneous multi-element detection, quick detection, and have good sensitivity and detection range (Suprapto, et al., 2016). The analysis results are shown in Table 3. Additionally, the mineral concentrations of the commercial seawater concentrate products are shown in Table 2.

Before analyzing the sample with XRF, the XRF instrument is calibrated using the "MCA calibration sample". The sample to be tested is then placed into the sample holder lined with special plastic film for XRF analysis, without requiring special preparation or standard solutions for each element. After setting the required conditions for analysis in the software, the results are awaited.

For ICP-OES analysis, calibration is performed using ready-to-use calibration solutions. The sample to be analyzed must undergo wet digestion due to its tendency to precipitate and the sensitivity of the instrument. First, 10 ml of the seawater concentrate sample and the comparison sample are placed into a digestion flask, followed by the addition of 3 ml of HCl and 1 ml of HNO3. Digestion is carried out with a heavy metal digester for 15 minutes at 95°C. The sample is then allowed to cool, filtered using Whatman No. 41 filter paper, and the digested sample is dissolved. The absorbance is then observed with ICP-OES to determine the content in the sample and comparison (Suprapto et al., 2016). For ICP-OES analysis, turn on the device and increase the Breaker High Voltage ICP. Activate the autosampler and open the ICP Expert II software. Allow the ICP to purge for 20 minutes. Turn on the water cooler. Ignite the plasma by clicking the plasma ON icon. Click the Torch Align menu and then Torch Scan. Close the instrument window. Create a method, read the standard and sample by clicking the worksheet menu. To print the analysis results, click the file menu and select report setting. To end the use of ICP-OES, exit the ICP Expert II software.

The mineral content in commercial products is shown in Table 3. This content is listed on the product packaging labels. The results indicate that the commercial seawater concentrate contains Mg, Na, K, Ca, and S. Based on these data, the seawater concentrate can meet the daily value (DV) for adults when consumed at 4.3 ml for Mg, 83.3 ml for Na, 203 ml for K, and 25,000 ml for Ca. There is no data available for the DV and upper intake limit for S. The commercial product states a serving size of 5 ml, which means it only meets the daily requirement for Mg and cannot be considered a primary source for daily mineral intake.

The analysis results of the Pamekasan Madura seawater concentrate and commercial products using XRF and ICP-OES are shown in Table 3. The XRF analysis of the comparison seawater concentrate revealed elements such as Mg, Si, S, Cl, K, Cr, Cu, Br, Rb, Sn, Ta, and Th, while the ICP-OES analysis showed elements such as Mg, K, Ca, Mn, Zn, As, Ag, and Bi. The XRF analysis of the Pamekasan Madura seawater concentrate found elements such as Mg, Si, S, Cl, K, Ca, Fe, Cu, Br, Rb, Sn, Te, Hf, and Ta, while the ICP-OES analysis showed elements such as Mg, K, Ca, Mn, and Ag.

The mineral content in the Pamekasan seawater concentrate that is needed and can meet the body's requirements includes Mg, Cl, K, Ca, Mn, Fe, and Cu. Additionally, heavy metals such as Hg, Pb, Cd, and As were not detected in the Pamekasan seawater concentrate, indicating its safety in terms of mineral content.

Only the elements potassium, magnesium, and calcium could be compared for correlation because only these elements were present in both methods with standard curves listed in the appendix. Potassium showed a high correlation with a correlation coefficient of 0.9933, while magnesium and calcium had very weak correlations with correlation coefficients of 0.038 and 0.1373, respectively.

When comparing the commercial seawater concentrate and the Pamekasan seawater concentrate, the commercial product contained more elements such as S, K, Cr, Mn, Zn, As, Ag, Sn, and Bi, while the sample contained more elements such as Mg, Si, Cl, Ca, Fe, Cu, Br, Rb, Hf, and Ta. The commercial seawater concentrate contained a small amount of As. For adults weighing 60 kg, the upper intake limit is 900 µg per week, or 22,500 ml of the commercial seawater concentrate per week. For other elements with upper intake limits, such as Ag and Sn, the upper intake for Ag is 54 µg per week, approximately 0.007 ml in the commercial product and 0.002 ml in the sample per week. For Sn, the upper intake for adults weighing 60 kg is 840 mg per week, or 93.6 ml in the commercial product and 84.2 ml in the sample per week.

In the XRF analysis results, the amount needed to meet the DV for Mg at the age range of 1-3 years is the same as the upper intake limit. For the age ranges of 7-9 years, 10 years, males >16 years, and females >19 years, the amount needed to meet the DV for Mg exceeds the upper intake limit. For other age ranges, it is below the upper intake limit. For Ca, Fe, and Cu, none exceed the upper intake limit. In the ICP-OES analysis results, the amount needed to meet the DV for Mg at the age range of 1-3 years is the same as the upper intake limit. For ages 10 years and males >19 years, the amount needed to meet the DV for Mg exceeds the upper intake limit. For Ca and Mn, none exceed the upper intake limit.

There are differences in the results between the mineral concentrations listed on the commercial seawater product labels, XRF, and ICP-OES. Similarly, there are differences in the analysis results between XRF and ICP-OES for the Pamekasan Madura seawater concentrate, both in terms of the type and number of elements. Statistical differences can be analyzed using the Statistical Product and Service Solutions (SPSS) program. First, a comparison is made for the commercial product with elements listed on the label, XRF, and ICP-OES, such as Mg, K, and Ca, as shown in Table 4.3. The Repeated Measure ANOVA method is used because there are more than two variables and it is a parametric statistical category. The requirement for parametric statistics is that the data must be normally distributed, with a significance value > 0.05. The normality test results show significance values of 0.514, 0.789, and 0.126, indicating that the data are normally distributed. The Mauchly’s Test of Sphericity output shows a significance value (Sig.) of 0.003 < 0.05, which does not meet the assumption of equal variances or data spread far from the mean. Thus, the SPSS analysis results should be interpreted with the Greenhouse-Geisser value in the Test of Within-Subjects Effects output.

In the Test of Within-Subjects Effects output, conclusions are drawn based on the hypothesis and decision criteria:

1. H0: There is no difference in the average analysis results of elements on the label, XRF, and ICP-OES in the commercial product. H0 is accepted if the Greenhouse-Geisser significance value (Sig.) is > 0.05.
2. H1: There is a difference in the average analysis results of elements on the label, XRF, and ICP-OES in the commercial product. H1 is accepted if the Greenhouse-Geisser significance value (Sig.) is < 0.05.

The Greenhouse-Geisser significance value (Sig.) is 0.390 > 0.05, thus H0 is accepted, indicating no difference in the average analysis results of elements on the label, XRF, and ICP-OES in the commercial product.

In the Pairwise Comparisons output, it is defined as follows:

1. When comparing the label with XRF, there is a difference of 10,980 ppm, with no significant difference since the significance value (Sig.) is 1 > 0.05.
2. When comparing the label with ICP-OES, there is a difference of 29,277.295 ppm, with no significant difference since the significance value (Sig.) is 1 > 0.05.
3. When comparing XRF with ICP-OES, there is a difference of 18,297.295 ppm, with no significant difference since the significance value (Sig.) is 1 > 0.05.

Next, a comparison of XRF and ICP-OES for the comparison and sample was performed using the Wilcoxon test. The Wilcoxon test is a nonparametric (qualitative) method used to determine the difference in average results between two paired samples. The Wilcoxon test outputs for the comparison and sample are shown in Tables 4 and 5, respectively. This method was chosen because the data are not normally distributed, with significance values of 0.001 < 0.05 for both the comparison and sample.

In the comparison output, the Negative Ranks indicate that the ICP-OES analysis results are lower than XRF for 2 elements. The Positive Ranks indicate that the ICP-OES analysis results are higher than XRF for 6 elements. The Ties indicate that there is no difference between ICP-OES and XRF for 0 elements. In the sample output, the Negative Ranks indicate that the ICP-OES analysis results are lower than XRF for 8 elements. The Positive Ranks indicate that the ICP-OES analysis results are higher than XRF for 2 elements. The Ties indicate that there is no difference between ICP-OES and XRF for 17 elements.

The Wilcoxon test statistics output for the comparison shows a significance value (Sig.) of 0.674 > 0.05, indicating no difference in average results between XRF and ICP-OES for the comparison. The sample test statistics output shows a significance value (Sig.) of 0.013 < 0.05, indicating a difference in average results between XRF and ICP-OES for the sample.

The differences in results between the two instruments can be attributed to the different treatments of the sample in XRF and ICP-OES analysis. In XRF analysis, the sample does not require digestion because XRF can analyze solid to liquid samples without prior digestion or dissolution. However, this leads to higher matrix effects that can influence the test results. Seawater concentrate is seawater that has been processed into a concentrated form, and when left standing, the water in the concentrate will precipitate. The sample contains solids, so it cannot be directly analyzed by ICP-OES. The sample must be in dissolved form, requiring digestion with acid. In this study, aqua regia consisting of HNO3 and HCl in a 1:3 ratio was used. Acid digestion can alter the form of elements, as some elements do not dissolve or ionize easily. Some metals can be bound in organic compounds or as mineral precipitates that are difficult to dissolve. Acid digestion can break down these complex compounds or minerals, freeing the elements. Due to the different treatments, the matrix composition of the sample can affect the results in XRF and ICP-OES, leading to differences in analysis results. Another factor is that XRF does not require standard solutions for each element, while ICP-OES requires standard solutions for each element to be analyzed, making the analysis dependent on the availability of standard solutions in the laboratory. XRF can detect more elements than ICP-OES. However, in terms of detection range, ICP-OES can detect at lower concentrations (0.0365 – 18625.8 mg/l), while XRF has a higher detection range (6.61 – 188319 mg/l). For detecting heavy metals in Pamekasan seawater concentrate, ICP-OES is better due to its lower detection range. For detecting more elements at high concentrations, XRF is preferable.

CONCLUSION

The results of the research indicate that the essential mineral content of the seawater concentrate from Pamekasan, Madura, includes Mg, Cl, K, Ca, Cr, Mn, Cu, and Zn. According to the statistical calculations using SPSS, the analysis results from XRF and ICP-OES show no significant difference in the average results for the comparison/commercial products, with Greenhouse-Geisser and Wilcoxon test significance (Sig.) values of 0.390 and 0.674, respectively. However, there is a significant difference in the average analysis results between XRF and ICP-OES for the Pamekasan seawater concentrate samples, with a Wilcoxon test significance (Sig.) value of 0.013. ICP-OES is more recommended due to its lower detection range of 0.0365 – 18625.8 mg/l, making it suitable for detecting elements at low concentrations, especially heavy metals. Additionally, since ICP-OES requires pretreatment, matrix interference can be reduced in ICP-OES analysis results.

REFERENCES

Agency for Toxic Substances and Disease Registry. 2023. Cadmium Toxicity: Biological Fate. [Diunduh 16 Juni 2023]. Tersedia dari https://www.atsdr.cdc.gov/csem/cadmium/Biological-Fate.html#:~:text=Cadmium%20has%20no%20known%20beneficial,Cadmium%20is%20a%20cumulative%20toxin.

Arif Susanto, Tri Mulyani, dan Sandi Nugraha. 2021. Validasi Metode Analisis Penentuan Kadar Logam Berat Pb, Cd dan Cr Terlarut dalam Limbah Cair Industri Tekstil dengan Metode Inductively Coupled Plasma Optical Emission Spectrometry Prodigy. *Jurnal Ilmu Lingkungan*.

Erian Febri Satriawan, Ita Widowati,Jusup Suprijanto. 2021. Pencemaran Logam Berat Kadmium (Cd) dalam Kerang Darah (Anadara granosa) yang Didaratkan di Tambak Lorok Semarang*". Journal of Marine Research.*

Food and Drug Administration. 2023. Arsenic in Food and Dietary Supplements. [diunduh 16 Juni 2023] Tersedia dari https://www.fda.gov/food/environmental-contaminants-food/arsenic-food-and-dietary-supplements

Menteri Kesehatan Republik Indonesia. 2019. Peraturan Menteri Kesehatan Republik Indonesia Nomor 28 Tahun 2019 Tentang Angka Kecukupan Gizi Yang Dianjurkan Untuk Masyarakat Indonesia. [Diunduh 27 Januari 2023] Tersedia dari:http://hukor.kemkes.go.id/uploads/produk_hukum/PMK_No28_Th_2019_ttg_Angka_Kecukupan_Gizi_Yang_Dianjurkan_Untuk_Masyarakat_Indonesia.pdf

Muhamad sehol, dkk 2022. Biologi Lingkungan". Pt Global Eksekutif Teknologi.

Megawati, E. ; S. ; S. I. Potensi Kombinasi Bittern Water dengan Vitamin B Kompleks untuk Terapi Defisiensi Mineral pada Sapi 2021: Studi Literatur. *J. Med. Vet.* **4**, 137–154 .

Purna Pirdaus, Miftahur Rahman, Rinawati, Ni Luh Gede Ratna Juliasih, Dian Pratama, Agung

Abadi Kiswandon. 2019. *Verifikasi Metode Analisis Logam Pb, Cd, Cr, Cu, Ni, Co, Fe, Mn Dan Ba Pada Air Menggunakan Inductivly Coupled Plasma-Optical Emission Spectrometer(ICP-OES). Analytical and Environmental Chemistry*.

Siti, Amirah. 2022 . *Potensi Hidroksiapatit Terkarbonasi Yang Disintesis Dari Precipitated Kalsium Karbonat (PCC) Dengan Metode Hidrotermal Untuk Penjernihan Air Ga*mbut.

Suprapto, Retty Dwi Kisnawati. 2016. Pemisahan Alumina Pada Residu Bauksit (Red Mud) Yang Berasal Dari Riau Dengan Metode Sintering Sodalime". *Jurnal Sains dan Seni.*

Sriwidodo, Umar, A.K., Megawati, E., Butarbutar, M.E.T., Wathoni, N., dan Alaydrus, S. 2020. Physicochemical Characterization of Concentrated Mineral and Magnesium Isolate of Sea Water Pamekasan Madura. *Int. J. Res. Pharm. Sci*. Vol. 11: 2154-2157.

Wani, A. L., Ara, A., & Usmani. 2015. *J. A. Lead toxicity: a review. Interdisciplinary toxicology*. Vol. 8(2): 55–64.

World Health Organization. 2017. Mercury and health. [Diunduh 16 Juni 2023]. Tersedia dari: https://www.who.int/news-room/fact-sheets/detail/mercury-and-health.