ABSTRAK

Penelitian ini bertujuan untuk mempelajari dinamika logam di lingkungan abiotik (air, tanah, dan sedimen) dan biotik (tanaman, ikan, dan manusia) di lahan pertanian bawang merah, termasuk analisis risiko keselamatan lingkungan dan kesehatan manusia dengan memperhatikan pengaruh perubahan musim dan sifat fisikokimia tanah serta melakukan pemodelan matematik untuk penyerapan logam oleh tanaman bawang merah. Penelitian dilakukan di 5 desa (Grinting, Kluwut, Bulakparen, Cimohong, dan Dukuhlo) yang berada di Kabupaten Brebes – Jawa Tengah. Penelitian dilakukan secara bertahap dengan cara melakukan analisis kandungan logam dalam pestisida maupun pupuk anorganik yang banyak digunakan oleh petani di sekitar daerah penelitian. Asesmen dinamika logam di lingkungan abiotik pada penelitian ini dilakukan dengan identifikasi kandungan logam dan distribusinya dalam tanah pertanian dan melakukan asesmen pengaruh musim terhadap dinamika logam dalam air irigasi maupun sedimen permukaan serta penilaian keselamatan lingkungan abiotik. Tahapan berikutnya adalah mempelajari pengaruh perbedaan musim terhadap penyerapan logam oleh tanaman bawang merah serta penilaian keamanan konsumsi hasil pertanian bawang merah bagi masyarakat sekitar. Pemodelan matematik untuk mempelajari penyerapan logam oleh tanaman bawang merah juga dipelajari untuk mengetahui dinamika logam dari komponen abiotik masuk ke komponen biotik di lingkungan. Dinamika logam pada komponen abiotik dan biotik lainnya dipelajari dengan melakukan asesmen kandungan logam di muara sungai pada daerah penelitian dan ikan yang hidup di daerah muara. Selain itu, dilakukan penilaian keselamatan lingkungan dan keamanan konsumsi ikan yang hidup di muara sungai. Tahapan terakhir pada penelitian ini yaitu kajian pengaruh penggunaan pestisida dan pupuk anorganik terhadap kesehatan para petani di daerah penelitian. Pada penelitian ini, analisis logam pada semua sampel dilakukan menggunakan metode Analisis Aktivasi Neutron (AAN). *Quality control* hasil analisis semua sampel dilakukan dengan menggunakan *Standard Reference Material* (SRM) produksi *National Institute of Standards and Technology* (NIST) dengan memperhatikan matriks sampel. Hasil analisis sampel pestisida diketahui bahwa pestisida yang banyak digunakan oleh petani bawang merah di Kab. Brebes mengandung *trace element* (Mg, Ti, Cl, Al, Ca, Br, Na, U, Mn, Br, La, Se, Hg, Rb, Fe, Eu, dan Sb), dan logam berat beracun (As, Co, Cr, Ni, Zn, Cu, Hg). Secara umum, pestisida padat mengandung konsentrasi unsur yang lebih tinggi daripada pestisida cair. Analisis sampel pupuk anorganik yang banyak digunakan oleh petani diketahui mengandung multi-nutrien, *trace elements*, dan logam berat yang dapat bersifat presisten di lingkungan. Pada tanah pertanian bawang merah terdeteksi unsur mayor (Mg, K, Na, Fe, Al, Mn, Ca, dan Ti), logam berat (Cu, Cr, As, Cd, Hg, Zn, dan Co), dan *trace elements* (V, Br, La, Se, Ba, Hf, Sr, Cs, Tb, Sc, Rb, Eu, Sb, Ta, U, Th, dan Sm). Kandungan logam berat Cd, Co, Cr, Cu, Mn, Zn, Fe, As dan Hg diketahui melebihi dari standar regulasi yang diterapkan oleh WHO/FAO untuk tanah pertanian. Berdasarkan indeks pencemaran polutan diketahui bahwa tanah pertanian bawang merah di Kabupaten Brebes, Jawa Tengah - Indonesia terkontaminasi unsur Se dan Cd sangat tinggi. Hasil analisis WQI diketahui bahwa kualitas air sungai pada musim penghujan lebih baik dibandingkan musim kemarau. Hasil analisis PCA pada dua musim yang berbeda, diketahui bahwa perubahan musim dapat mempengaruhi parameter sifat fisikokimia air serta kandungan logam berat dan

trace elements dalam air irigasi. Hasil analisis sedimen permukaan diketahui bahwa terdeteksi 32 unsur dalam sedimen (Mg, Al, Ca, Na, K, Fe, Ti, Mn, U, V, Cu, Sm, Br, As, La, Se, Th, Cr, Ba, Hf, Sr, Sc, Rb, Zn, Co, Eu, Sb, Cd, Hg, Cs, Tb, dan Ta). Perubahan musim dapat mempengaruhi sifat fisikokimia sedimen dan kandungan unsur-unsur dalam sedimen. Pola sebaran *trace elements* dalam sedimen sangat dipengaruhi oleh sifat fisikokimia sedimen dan perubahan musim, dimana penyebaran dominan di daerah muara sungai. Berdasarkan nilai $I_{geo,}$ diketahui bahwa sistem perairan terkontaminasi unsur As, dan Se. Penilaian PLI menunjukkan bahwa beban polutan dalam sedimen pada musim kemarau lebih tinggi dibandingkan musim penghujan, hal ini dapat juga disebabkan oleh faktor fisikokimia sedimen. Berdasarkan analisis PCA dapat diketahui beberapa kelompok *trace elements* diduga masuk ke dalam lingkungan dari sumber yang sama. Perbedaan musim mempengaruhi sifat fisikokimia tanah dan distribusi serta mobilitas *trace elements* dan logam berat dalam tanah serta translokasinya pada tanaman. Pada musim hujan nilai BAF logam berat relatif lebih rendah dibandingkan pada musim kemarau. Identifikasi risiko dan penilaian risiko kesehatan manusia yang dilakukan terhadap unsur-unsur yang bersifat *toxic* dimana mempunyai nilai *Target Hazard Quotient* (THQ) dan *Hazard Index* (HI) yang lebih rendah dari 1 untuk semuanya, baik pada musim hujan maupun kemarau sehingga dapat dinyatakan hasil pertanian bawang merah aman dikonsumsi oleh masyarakat. Parameter kandungan logam dalam tanah, pH, CEC, Eh, kandungan *clay*, *sand* dan *silt* cocok digunakan sebagai parameter untuk menentukan model simulasi penyerapan logam oleh tanaman bawang merah (nilai $p<0,05$). Model prediksi yang dihasilkan untuk simulasi konsentrasi logam dalam jaringan bawang merah, berkinerja baik dengan efisiensi cukup tinggi dan kesalahan rendah. Hasil evaluasi kualitas sedimen berdasarkan nilai CF, EF, dan I_{geo}, diketahui bahwa muara sungai di daerah Grinting mengalami kontaminasi sangat tinggi, pengayaan yang sangat signifikan dan pencemaran berat untuk unsur As, Se dan Cd. Evaluasi sedimen berdasarkan nilai PLI dan PERI diketahui bahwa muara sungai Grinting mengalami pencemaran logam berat dan *trace elements*. Hasil analisis kandungan rerata logam berat dan *trace elements* dalam insang>tulang>kulit>daging>otak ikan. Nilai EDI secara signifikan lebih rendah dari nilai *Tolerable Daily Intake* (TDI). Nilai *Target Hazard Quotient* (THQ), *Hazard index* (HI) dan *Target Carcinogenic Risk* (TR) menunjukkan tidak ada risiko bahaya dari konsumsi ikan di muara sungai Grinting bagi masyarakat sekitar. Hasil analisis rambut petani mengandung logam berat (As, Hg, Cr, Cu, Al, Mn, V, Fe, Zn, dan Co) dan *trace elements* (Mg, Ca, Br, Na, La, Se, Th, dan Sc). Kandungan rambut petani lebih tinggi dibandingkan rambut non-petani. Berdasarkan uji korelasi koefisien Pearson diketahui bahwa penggunaan pestisida dan pupuk anorganik dapat meningkatkan konsentrasi logam berat dan *trace elements* pada rambut petani.

ABSTRACT

This study aims to study the metal dynamics of the abiotic (water, soil, and sediment) and biotic (plant, fish, and human) environments in a shallot farming area. It includes a safety risk analysis of the environment and human health by taking into account the influence of seasonal changes and soil physicochemical properties, as well as conducting mathematical modelling for metal uptake by shallot plants. This research was performed in the five villages (Grinting, Kluwut, Bulakparen, Cimohong, and Dukuhlo) located in Brebes District, Central Java. It was carried out gradually by analyzing the metal content of pesticides and inorganic fertilizers that are widely used by farmers around the study area. Furthermore, to determine the metal dynamics of the abiotic environment, the assessment of metal content and its distribution in agricultural soil for major, minor, and trace elements was carried out in this study. By considering the influence of the season, an assessment of metal content and its distribution in irrigation water and surface sediment was also conducted. At this stage, an abiotic environmental safety assessment was also performed. The next stage was to study the effect of seasonal differences on metal uptake by shallot plants and assess the consumption safety of shallot agricultural products for the surrounding community. The mathematical modelling to study the metal uptake by shallot plants was also studied to find out the metal dynamics from abiotic components entering into biotic components in the environment. The metal dynamics of other abiotic and biotic components were studied by assessing the metal content in the river estuary of the study area and the fish living around it. In addition, an assessment of environmental safety and the safety of fish consumption in river estuaries was carried out. The last stage of this research was to study the effect of pesticide and inorganic fertilizer utilization on the health of farmers in the research area. In this study, metal analysis of all samples was performed using the Neutron Activation Analysis (NAA) method. Quality control of the analysis results of all samples was carried out using Standard Reference Material (SRM) produced by the National Institute of Standards and Technology (NIST) by taking into account the sample matrix. The analysis results of pesticide samples found that pesticides widely used by shallot farmers in Brebes district contain trace elements (Mg, Ti, Cl, Al, Ca, Br, Na, U, Mn, Br, La, Se, Hg, Rb, Fe, Eu, and Sb) and toxic heavy metals (As, Co, Cr, Ni, Zn, Cu, and Hg). Generally, solid pesticides contain higher concentrations of elements than liquid pesticides. Analysis of samples of inorganic fertilizers that are widely used by farmers is known to contain multi-nutrients, trace elements, and heavy metals that can be resistant to the environment. In the shallot farming area, major elements (Mg, K, Na, Fe, Al, Mn, Ca, and Ti), heavy metals (Cu, Cr, As, Cd, Hg, Zn, and Co), and trace elements (V, Br, La, Se, Ba, Hf, Sr, Cs, Tb, Sc, Rb, Eu, Sb, Ta, U, Th, and Sm) were detected. The heavy metal content of Cd, Co, Cr, Cu, Mn, Zn, Fe, As, and Hg was found to exceed the regulatory standards applied by WHO/FAO for agricultural soils. Based on the pollutant pollution index, it was known that the shallot agricultural soil in Brebes district, Central Java, Indonesia, was contaminated with very high levels of Se and Cd. The results of the WQI analysis found that the quality of river water in the rainy season was better than in the dry season. Based on the results of PCA analysis in two different seasons, it was known that seasonal changes can affect the parameters of the

physicochemical properties of water as well as the content of heavy metals and trace elements in irrigation water. The analysis results of surface sediment found that 32 elements were detected in the sediment (Mg, Al, Ca, Na, K, Fe, Ti, Mn, U, V, Cu, Sm, Br, As, La, Se, Th, Cr, Ba, Hf, Sr, Sc, Rb, Zn, Co, Eu, Sb, Cd, Hg, Cs, Tb, and Ta). Seasonal changes can affect the physicochemical properties of sediments and the content of elements in sediments. The distribution pattern of trace elements in sediments was strongly influenced by the physicochemical properties of sediments and seasonal changes, where the distribution was dominant in estuary areas. Based on I_{geo} values, it was known that the aquatic system was contaminated by As and Se elements. PLI values show that the pollutant load of sediments in the dry season was higher than in the rainy season. It can also be caused by physicochemical factors in sediments. Based on PCA analysis, it can be concluded that several groups of trace elements allegedly entered the environment from the same source. Seasonal differences affect soil physicochemical properties, the distribution and mobility of trace elements and heavy metals in soil, and their translocation in plants. In the rainy season, the BAF value of heavy metals was relatively lower than in the dry season. Risk identification and human health risk assessment were performed on toxic elements that have Target Hazard Quotient (THQ) and Hazard Index (HI) values lower than 1 for all, both in the rainy and dry seasons, so that shallot agricultural products can be declared safe for consumption by the community. The parameters of metal content in soil, pH, CEC, Eh, clay, sand, and silt contents were suitable to be used as parameters in determining a simulation model for metal uptake of shallot plants (p value <0.05). The prediction model obtained for simulating the metal concentration of shallot tissues performed well with fairly high efficiency and low error. From the evaluation result of sediment quality based on CF, EF, and Igeo values, it was known that the river estuary of the Grinting area experiences very high contamination, very significant enrichment, and heavy contamination for the elements As, Se, and Cd. Sediment evaluation based on PLI and PERI values shows that the Grinting river estuary was polluted by heavy metals and trace elements. The results of the analysis of the average content of heavy metals and trace elements in fish were gills>bones>skin>muscle>brain. The EDI value was significantly lower than the Tolerable Daily Intake (TDI) value. The Target Hazard Quotient (THQ), Hazard Index (HI), and Target Carcinogenic Risk (TR) values show that there is no risk of harm from consuming fish at the Grinting river estuary for the surrounding community. The analysis results of farmers' hair contained heavy metals (As, Hg, Cr, Cu, Al, Mn, V, Fe, Zn, and Co) and trace elements (Mg, Ca, Br, Na, La, Se, Th, and Sc). The hair content of farmers was higher than non-farmer hair. Based on the Pearson coefficient correlation test, it was found that the use of pesticides and inorganic fertilizers can increase the concentration of heavy metals and trace elements in farmers' hair.