

TABLE OF CONTENTS

STATEMENT OF PLAGIARISM FREE	i
ACKNOWLEDGEMENT	ii
ABSTRACT.....	iii
<i>SARI</i>	iv
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	x
LIST OF FIGURES	xi
LIST OF ABBREVIATION	xvii
CHAPTER 1 INTRODUCTION	1
1.1. Background	1
1.2. Research Question.....	3
1.3. Objectives.....	3
1.4. Scope and Limitation	3
1.4.1. Scope.....	3
1.4.2. Limitations	4
1.5. Significance to knowledge	4
1.6. Previous Studies on heavy metals contamination in Yogyakarta	5
1.7. Research Authenticity	5
CHAPTER 2 LITERATURE REVIEW	7
2.1. Urbanization: a case of Yogyakarta, Indonesia.....	7
2.2. Regional Geology.....	8
2.2.1. Current Tectonic Setting.....	8
2.2.2. Geology of Yogyakarta Special Region	10
2.2.3. Merapi Volcanics (Parent Material)	11
2.3. Soil Classification	13
2.3.1. Soil Orders and Taxonomy.....	13
2.3.2. Soil Horizon.....	15
2.3.3. Soil Types in Yogyakarta Region.....	17
2.3.4. Soil into Urban Soil	18
2.4. Heavy metals in urban soils	18
2.4.1. Lead (Pb) as a heavy metal contaminant.....	19
2.4.2. Copper (Cu) as a heavy metal contaminant.....	19
2.4.3. Cadmium (Cd) as a heavy metal contaminant.....	20

2.4.4. Zinc (Zn) as a heavy metal contaminant	20
2.5. Heavy metals contamination in urban soils: Engineering perspective.....	21
2.5.1. Relevance to Shallow Foundation Infrastructure	22
2.6. Hypothesis.....	22
CHAPTER 3 METHODOLOGY	23
3.1. Research Approach	23
3.1.1. Study Flow Chart.....	23
3.2. Setting and Sampling	24
3.2.1. Study Area	24
3.2.2. Sampling.....	25
3.2. Elemental Analysis.....	26
3.2.1. Laboratory (ICP-AES).....	26
3.2.2. Sample Preparation.....	26
3.3. Environmental Parameters	27
3.3.1. Assessment of heavy metals	27
3.3.2. Calculation of Indices	27
3.4. Geostatistical Mapping and Analysis.....	29
3.4.1. Empirical Bayesian Kriging (EBK).....	29
3.4.2. Inverse Distance Weighted (IDW)	30
3.4.3. Statistical Analysis	30
3.5. Urbanization Projections	32
3.5.1. LULC.....	33
3.5.2. Digitization and Field Survey.....	33
3.5.3. Database Verification (Secondary).....	34
3.5.4. EVI Cells	34
3.6. Physio-Mechanical Studies	35
3.6.1. Heavy Metal Selection	37
3.6.2. Test Material (Background Soil).....	37
3.6.3. Soil pH in the Field and Laboratory	38
3.6.4. Soil Mineralogy (X-Ray Diffraction Analysis).....	39
3.6.5. Parent Material (Petrographic Analysis)	39
3.6.6. Experimental Contamination.....	40
3.6.7. Geotechnical Test	40
3.6.8. Contamination Vertical Profiling	43
CHAPTER 4 SPATIAL ANALYSIS OF HEAVY METALS	46



4.1. Heavy Metals: Data Overview	46
4.2. Empirical Bayesian Kriging (EBK)	47
4.2.1 Spatial distribution of Lead (Pb)	47
4.2.2. Spatial distribution of Copper (Cu)	52
4.2.3. Spatial distribution of Cadmium (Cd)	58
4.2.4. Spatial distribution of Zinc (Zn).....	65
4.3. Inverse Distance Weighted (IDW).....	71
4.3.1. Spatial distribution of Lead (Pb)	71
4.3.2. Spatial distribution of Copper (Cu)	73
4.3.3. Spatial distribution of Cd (Cd)	76
4.3.4. Spatial distribution of Zn (Zn).....	79
4.3. Heavy Metals Environmental Parameters (Indices).....	82
4.3.1. Assessment of Environmental Indices.....	82
4.3.3. Environmental Implication of Heavy metals.....	83
4.4. Heavy Metals Pattern-Correlation.....	84
4.4.1. Pattern to Land Use and Land Cover	85
4.4.2. Pattern to Important Features	88
4.4.3. Pattern to Enhanced Vegetation Index (EVI).....	90
4.5. Relevance to International Health Guidelines.....	93
4.6. Synthesis	94
CHAPTER 5 PHYSIO-MECHANICAL BEHAVIOR OF CONTAMINATED SOIL	96
5.1. Lead (Pb) as Contaminant in Urban Soil	96
5.2. Background Soil (Selection)	96
5.2.1. Soil Survey (Soil Order).....	96
5.2.2. Soil pH.....	97
5.2.3. Soil Mineralogy	98
5.2.4. Parent Material (Soil)	100
5.3. Physio-mechanical Assessment of Background Soil	101
5.3.1. Grain Size distribution.....	101
5.3.2. Soil Texture Classification	102
5.3.3. Physical Properties	103
5.3.4. Permeability.....	104
5.4. Contamination Rationale.....	105
5.5. Physio-mechanical Behaviour of Urban Soil.....	105
5.5.1. Compaction capability	105



5.5.2. Mechanical Strength Capability	108
5.5.3. Contamination adsorption complexity	111
5.5.4. Behaviour Prediction	112
5.6. Relevance to Shallow Foundation.....	113
CHAPTER 6 CONCLUSION AND RECOMMENDATION	116
6.1. Conclusion.....	116
6.1.1. Urbanization: Spatial Distribution and Pattern of Heavy Metals	116
6.1.2. Effects of Heavy Metals to Urban Soil Physio-mechanical Behaviour	117
6.2. Recommendation.....	118
6.2.1 Sustainable Development Insights	119
BIBLIOGRAPHY	120
APPENDIX.....	130
APPENDIX A: SUPPLEMENTAL THEORY	130
APPENDIX B: RELEVANT DATA INPUT	131
APPENDIX C: RELEVANT DOCUMENTATION	147

LIST OF TABLES

Table 2.1	Soil Taxonomy Hierarchy (Baillie, 2001).....	14
Table 2.2	Basic Soil Orders (Hempel, 2014).....	15
Table 3.1	Background value (B_n) for soil heavy metals from Wulaningsish, 2009.....	28
Table 3.2	Working parameters of AAS.....	45
Table 4.1	Summary statistics of heavy metals concentration (mg/kg) in soils.....	46
Table 4.2	Summary for heavy metals (mg/kg) values of Pollution Index (PI), Geo-accumulation Index (I_{geo}), and Pollution Load Index (PLI).....	83
Table 4.3	Soil heavy metal concentration in soils guideline values based on various international standards (adapted from Alloway, 2013).....	94
Table 5.1	pH value representation of Background soil in field and laboratory readings, in comparison with average pH readings of 168 urban soils.....	98
Table 5.2	Background Soil Grain size analysis distribution.....	102
Table 5.3	Background Soil Texture fractions normalized into USDA Soil Texture classification (USDA, 2017).....	102
Table 5.4	Physical properties description of Background Soil.....	104
Table 5.5	Permeability of Background Soil.....	104
Table 5.6	Plastic Limit, Liquid Limit and Plastic Index of 4 soil variables.	113

LIST OF FIGURES

Figure 2.1	Urban vs Rural Population trend in Indonesia (UN DESA, 2018), modification: urbanet.info	7
Figure 2.2	Tectonic setting and geographical description of Indonesia and surrounding regions. In here, Indonesia (green), neighboring countries (gray), volcanoes (red triangle), and red arrow (plate movement vectors). Source: (Hall, 2009)	9
Figure 2.3	Geological map of Yogyakarta Special Region, Indonesia. In here also shows lineation structures (red lines: OF – Opak Fault), historical earthquakes (blue dots – intermediate depths, green dots – shallow depths).Source:(Handayani,2019)	11
Figure 2.4	Geologic Evolution of Merapi volcano. In reference, 1:50 000 Geological Map produced by Wirakusumah et al., (1989) and Stratigraphic interpretation by Gertisser et al., (2012).....	12
Figure 2.5	Soil Horizons, this is an idealized soil profile from a humid climate. Illustration by Tarbuck et al., (2019)	16
Figure 3.1	Thesis flow Chart	24
Figure 3.2	Topographic contours of the study area. Yogyakarta metropolis is surrounded by elevated areas of Kulon Progo (west) and Gunung Kidul (east), at north is Mt. Merapi.	25
Figure 3.3	Location of Samples in Yogyakarta metropolis, Indonesia	26
Figure 3.4	Algorithm Cell Calculation Reference. A. Shows the NDVI dynamic range figure showing saturation problems that curves the cell (atmosphere & soil influence anomalies). B. blue band of interest of EVI dynamic range working well below 0.1 value representing most surfaces in algorithm. C and D shows unstable cell values if blue band starts to increase to 0.2. Cell/Pixel illustration from (Justice et al., 1998).....	35
Figure 3.5	Experimental workflow of the study	37
Figure 3.6	Obtaining field pH value of the soil using Soil pH analyzer.....	38
Figure 3.7	Soil pH analysis in the laboratory.....	39

Figure 3.8	Location of samples selected for contamination vertical profiling....	43
Figure 3.9	Atomic Absorption Spectroscopy (AAS) running in calibration. Small tube is attached to the machine and submerge to deionized water for at least 10 seconds reading.....	45
Figure 4.1	Spatial distribution EBK map of Lead (Pb) concentration.....	47
Figure 4.2	A simulation of Pb selected site run using Empirical Bayesian Kriging method (Midwest of Yogyakarta City – Figure 4.3). In here, a neighbourhood standard circle is implemented with a maximum of 15 neighbours, and minimum of 10 neighbours of contamination soil sampling points. The standard circle (i.e., neighbourhood-type) has a radius of 2,516 meters. Refer to Figure 4.3 for graphical data.....	48
Figure 4.3	Empirical Bayesian Kriging simulation plots of Pb concentration: (a) Semivariogram, (b) Nugget effect, (c) Slope, and (d) Power.....	49
Figure 4.4	Cross-validation plots by Regression function and Quantile confirmation of Pb concentration: (a) Error, (b) Standardized Error, (c) Predicted, and (d) Normal Q-Q Plot.....	51
Figure 4.5	Cross-validation plots in terms of distribution trend plot analysis of Pb concentration values: (a) Distribution Error, (b) Distribution Measured & Predicted, (c) Distribution Validation Quantile, and (d) Distribution: Continuous Ranked Probability Score (CRPS).....	52
Figure 4.6	Spatial distribution EBK map of Copper (Cu) concentration.....	53
Figure 4.7	A simulation of Cu selected site run using Empirical Bayesian Kriging method (Southeast of Yogyakarta City – Figure 4.6). In here, a neighbourhood standard circle is implemented with a maximum of 15 neighbours, and minimum of 10 neighbours of contamination soil sampling points. The standard circle (neighbourhood-type) has a radius of 2,516 meters. Refer to Figure 4.8 for graphical data.....	54
Figure 4.8	Empirical Bayesian Kriging simulation plots of Cu concentration: (a) Semivariogram, (b) Nugget effect, (c) Slope, and (d) Power.....	55

Figure 4.9	Cross-validation plots by Regression function and Quantile confirmation of Cu concentration: (a) Error, (b) Standardized Error, (c) Predicted, and (d) Normal Q-Q Plot.....	57
Figure 4.10	Cross-validation plots in terms of Distribution trend plot analysis of Cu concentration values: (a) Distribution Error, (b) Distribution Measured & Predicted, (c) Distribution Validation Quantile, and (d) Distribution: Continuous Ranked Probability Score (CRPS).....	58
Figure 4.11	Spatial distribution EBK map of Cadmium (Cd) concentration.....	59
Figure 4.12	A simulation of Cd selected site run using Empirical Bayesian Kriging method (Northwest of Yogyakarta City – <i>Figure 4.11</i>). In here, a neighbourhood standard circle is implemented with a maximum of 15 neighbours, and minimum of 10 neighbours of contamination soil sampling points. The standard circle (neighbourhood-type) has a radius of 2,516 meters. Refer to Figure 4.13 for graphical data.....	60
Figure 4.13	Empirical Bayesian Kriging simulation plots of Cd concentration: (a) Semivariogram, (b) Nugget effect, (c) Slope, and (d) Power.....	61
Figure 4.14	Cross-validation plots by Regression function and Quantile confirmation of Cd concentration: (a) Error, (b) Standardized Error, (c) Predicted, and (d) Normal QQ Plot.....	63
Figure 4.15	Cross-validation plots in terms of Distribution trend plot analysis of Cd concentration values: (a) Distribution Error, (b) Distribution Measured & Predicted, (c) Distribution Validation Quantile, and (d) Distribution: Continuous Ranked Probability Score (CRPS).....	64
Figure 4.16	Spatial distribution EBK map of Zinc (Zn) concentration.....	65
Figure 4.17	A simulation of Zn selected site run using Empirical Bayesian Kriging method (east of Sleman from study area map – <i>Figure 4.16</i>). In here, a neighbourhood standard circle is implemented with a maximum of 15 neighbours, and minimum of 10 neighbours of contamination soil sampling points. The standard circle (neighbourhood-type) has a radius of 2,516 meters. Refer to Figure 4.18 for graphical data.....	66

Figure 4.18	Empirical Bayesian Kriging simulation plots of Zn concentration: (a) Semivariogram, (b) Nugget effect, (c) Slope, and (d) Power.....	67
Figure 4.19	Cross-validation plots by Regression function and Quantile confirmation of Zn concentration: (a) Error, (b) Standardized Error, (c) Predicted, and (d) Normal QQ Plot.....	69
Figure 4.20	Cross-validation plots in terms of Distribution trend plot analysis of Zn concentration values: (a) Distribution Error, (b) Distribution Measured & Predicted, (c) Distribution Validation Quantile, and (d) Distribution: Continuous Ranked Probability Score (CRPS).....	70
Figure 4.21	Spatial distribution IDW map of Lead (Pb) concentration.....	71
Figure 4.22	Cross-validation plots by Regression function to validate Pb concentration using plots of values in terms of (a) Error, and (b) Predicted.....	72
Figure 4.23	Cross-validation plots in terms of Distribution trend analysis of Pb concentration values: (a) Distribution Error, and (b) Distribution Measured & Predicted.....	73
Figure 4.24	Spatial distribution IDW map of Copper (Cu) concentration.....	74
Figure 4.25	Cross-validation plots by Regression function to validate Cu concentration using plots of values in terms of (a) Error, and (b) Predicted.....	75
Figure 4.26	Cross-validation plots in terms of Distribution trend analysis of Cu concentration values: (a) Distribution Error, and (b) Distribution Measured & Predicted.....	76
Figure 4.27	Spatial distribution IDW map of Cd (Cd) concentration.....	77
Figure 4.28	Cross-validation plots by Regression function to validate Cd concentration using plots of values in terms of (a) Error, and (b) Predicted.....	78
Figure 4.29	Cross-validation plots in terms of Distribution trend analysis of Cd concentration values: (a) Distribution Error, and (b) Distribution Measured & Predicted.....	78
Figure 4.30	Spatial distribution IDW map of Zinc (Zn) concentration.....	79

Figure 4.31	Cross-validation plots by Regression function to validate Zn concentration using plots of values in terms of (a) Error, and (b) Predicted.....	80
Figure 4.32	Cross-validation plots in terms of Distribution trend analysis of Zn concentration values: (a) Distribution Error, and (b) Distribution Measured & Predicted.....	81
Figure 4.33	World Historical Land Use and Land Cover (LULC), year 1850. Modified and Data source from archive of NASA, recorded and compiled by Goldewijk, (2010).....	85
Figure 4.34	Generalized Land Use and Land Cover of Yogyakarta metropolis, year 2021. Modified from LULC of ESRI Atlas built by Karra et al., (2021).....	87
Figure 4.35	Traffic Points, Transport Points, and major Gasoline Stations as contamination important contributor to Lead (Pb), overlay with Pb IDW spatial distribution map for visualization purposes of hotspots..	89
Figure 4.36	Road Density Map of Yogyakarta metropolis.....	90
Figure 4.37	Enhanced Vegetation Index (EVI) map of Yogyakarta metropolis, year 2000. Calculated data represented by each cell for accuracy purposes.....	91
Figure 4.38	Enhanced Vegetation Index (EVI) map of Yogyakarta metropolis, year 2021. Calculated data represented by each cell for accuracy purposes.....	93
Figure 5.1	Generalized Soil Profile of Background soil.....	97
Figure 5.2	XRD readings of background soil in plot reflection to Aluminosilicate (Al:Si) structure, Al:Si structure. Reference: International Centre for Diffraction Data (ICDD) (Gates-Rector & Blanton, 2019).....	99
Figure 5.3	XRD readings of background soil in alignment plot with Mica Group, Mineral as reference obtained from International Centre for Diffraction Data (ICDD) (Gates-Rector & Blanton, 2019).....	100

Figure 5.4	Petrographic snap (XPL – Cross-Polarized light) of rock present in the sampling soil profile. Identified minerals: Plg – plagioclase, Bt – biotite (mica), Pyx - pyroxene and gl – glass.....	101
Figure 5.5	Background soil identified as Sand using USDA Soil Texture Classification (USDA, 2017).....	103
Figure 5.6	Compaction curve of BG, S1K, S5k, and S10K.....	106
Figure 5.7	Trend analysis of BG, S1K, S5k, and S10K as per Pb contamination against Maximum dry density.....	107
Figure 5.8	Deviator Stress and Maximum strength plot of BG, S1K, S5k, and S10K.....	109
Figure 5.9	Pb contamination and Maximum strength plot of BG, S1K, S5k, and S10K as per assigned number of Deviator stress (50 kPa, 100 kPa, and 150 kPa).....	110
Figure 5.10	Pb contamination and Cohesion trend analysis plot of BG, S1K, S5k, and S10K.....	111
Figure 5.11	A scenario where Pb ion enters into outer sphere thru water films and connects to inner-sphere where it drives soil particle structures changes. Modified from (Nikkhah Nasab & Abdeh Keykha, 2020)...	112
Figure 5.12	Pb contamination vertical profiling from AAS results in (2) selected hotspots representative (T-77 and T-92) of Yogyakarta metropolis.....	114
Figure 5.13	Pb contamination vertical profiling from ICP-AES results in (2) selected hotspots representative (T-77 and T-92) of Yogyakarta metropolis.....	115

LIST OF ABBREVIATION

- AAS – Atomic Absorption Spectroscopy
- Cd – Cadmium
- Cu – Copper
- EBK – Empirical Bayesian Kriging
- EVI – Enhanced Vegetation Index
- IDW – Inverse Distance Weighted
- Igeo – Geoaccumulation Index
- ICP – AES – Inductively Coupled Plasma Atomic Emission Spectroscopy
- ICDD – International Council for Diffraction Data
- IUSS – International Union of Soil Sciences
- LULC – Land Use and Land Cover
- Pb – Lead
- PI – Pollution Index
- PLI – Pollution Load Index
- SDG – Sustainable Development Goal
- U.N. – United Nations
- USDA – United States Department of Agriculture
- Zn – Zinc
- XRD – X-Ray Diffraction