Assessment of e-Waste Disposal in Pakistan & Development of a Strategy for its Effectiveness

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Abstract

E-waste contains obsolete and discarded e-goods. Pakistan being technology-follower (refurbishers) import second-hand e-products from developed countries for recycling purposes. Problem arises when these become useless for even developing nation, then its fate is a question mark. Discarded e-items are sold to junkmen (collectors) at cheap rate per kg, who (dismantlers) get useful chips and accessories, avoiding reverse-logistics concept by the manufacturers. Rest of waste (extractors) is burnt (generate dioxins and hydrocarbons etc), to extract useful metals like Cu and Al, then seeping waste liquid (contains contaminants like Cr and Ni) into domestic drains directly going to rivers and Arabian Sea, thus polluting the environment (air, soil and water).

Keywords: obsolete; technology follower; toxic colonialism; burning; environment; legislation

Introduction

E-waste commonly consists of all obsolete and discarded electrical and electronics items which have spent their usage life and no more useful due to technology upgradation like printers, scanners, cell phones, telephone exchanges, photo copier machines and accessories linked with personal computers etc.

Jim Puckett of Greenpiece has elaborated Toxic Colonialism in detail i.e. electrical and electronic waste export to developing and under-developed nations like Pakistan, Bangladesh, India, and Sri Lanka etc. [1]

The entire globe specially developed countries generate 40~50 million tonnes of electronic garbage annually, and out of which 20-30% is extremely dangerous but recycled safely. This e-waste has a monetary value due to its metals and costly elements such as Copper (Cu), Aluminium (Al), Silver (Ag), Lead (Pb), Tin (Sn), Gallium (Ga), Mercury (Hg), and Crystalline etc. [2] It is found that anything which has a circuitry can be called as e-waste. [3]

A case study was held at Guiyu, which is one the main recycling centre in Guangdong for e-waste in China since 1995 [4]. The area has a population of 150,000, out of which mostly are immigrants and associated with e-waste recycling industry [5]. E-waste handling and recycling are the factors affecting the environments of this area as:

- Water: E-waste pollutants enter Nanyang river causing severe increase of polybrominated diphenyl (PBDE) in the silt ranges up to 16,000 ng/g. [6]
- Air: pollutants are spread into air through moisture around this recycling industry, causing breath and skin issues. An air test was conducted in the area revealed that Guiyu contain highest Poly-Chlorinated Dibenzo-p-dioxins and Dibenzofurans (PCDDs) i.e. around 2765 pg/m^3 [7] similarly burning of e-waste has brought PBDEs level upto 16,575 pg/m^3 i.e. 300 times higher than a specimen taken from Hong Kong. [8]
- Soil: Corrosive filtering was conducted to extract useful metals, leaving behind PBDEs of around 25,479 ng/g in a cultivated farmland near to this area, thus polluting the vegetable and fruit plants. Rice examination was also conducted in Zhejiang to verify the prior results shown that the rice has 2 to 4 times more Pb and Cd group elements. [4]
- Human: dioxins extraction in this area has brought about 15 – 56 times more than World Health Organization recommends maximum consumption [9]. Human hair investigation in Taizhou shown Poly-Brominated Biphenyls (PBBs), PBDEs levels i.e. 58ng/g and 30ng/g respectively [10] and same kind of dioxin levels found in human breast milk around Guiyu. [11]

Principle Issue/Obstacles of e-Waste

- There is no proper national regulation in Pakistan
- Trans-boundary movement like Afghanistan Transit Trade Agreement (ATTA) which allows totally free trade between Pakistan and Afghanistan [12]
- Un-safe handling/dismantling procedures allows potential environmental contaminants as already mentioned as costly elements
- Transfer of Technology for e-waste handing/dismantling is not available [13]
- Changing nature of e-waste due to high-technology advancements like CRT (which contains Pb) monitor replaced with LCDs (which contains Hg) [14]

Focused Interviews (for Qualitative Analysis)

These kinds of interview were conducted by the researcher in the government institutes (as shown in Table 1) for filling up qualitative questionnaire to begin his research/field work.

Research Gap

After extensive literature review and qualitative analysis, the researcher synthesized and short listed 10 main factors along with 37 sub-factors as follows:

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- "National Regulation (NR)
- Handling & Dismantling procedures (HD)
- E-waste Categorization (WC)
- Public awareness (PA)
- Role of Scrappers (RS)
- E-waste Disposal by OEMs
- Reduction of Hazardous Substances (RoHs)
- International Responsibility (IR)
- Monetary value of e-goods (MV)
- E-waste Management (EWM)"

RESEARCH MATERIAL AND METHODS

Figure 1 shows the schematic diagram of e-waste in Pakistan, starting from e-Waste generated by developed countries till approach formation in Pakistan through four categories like Collector, Refurbisher, Dismantler, and Extractor

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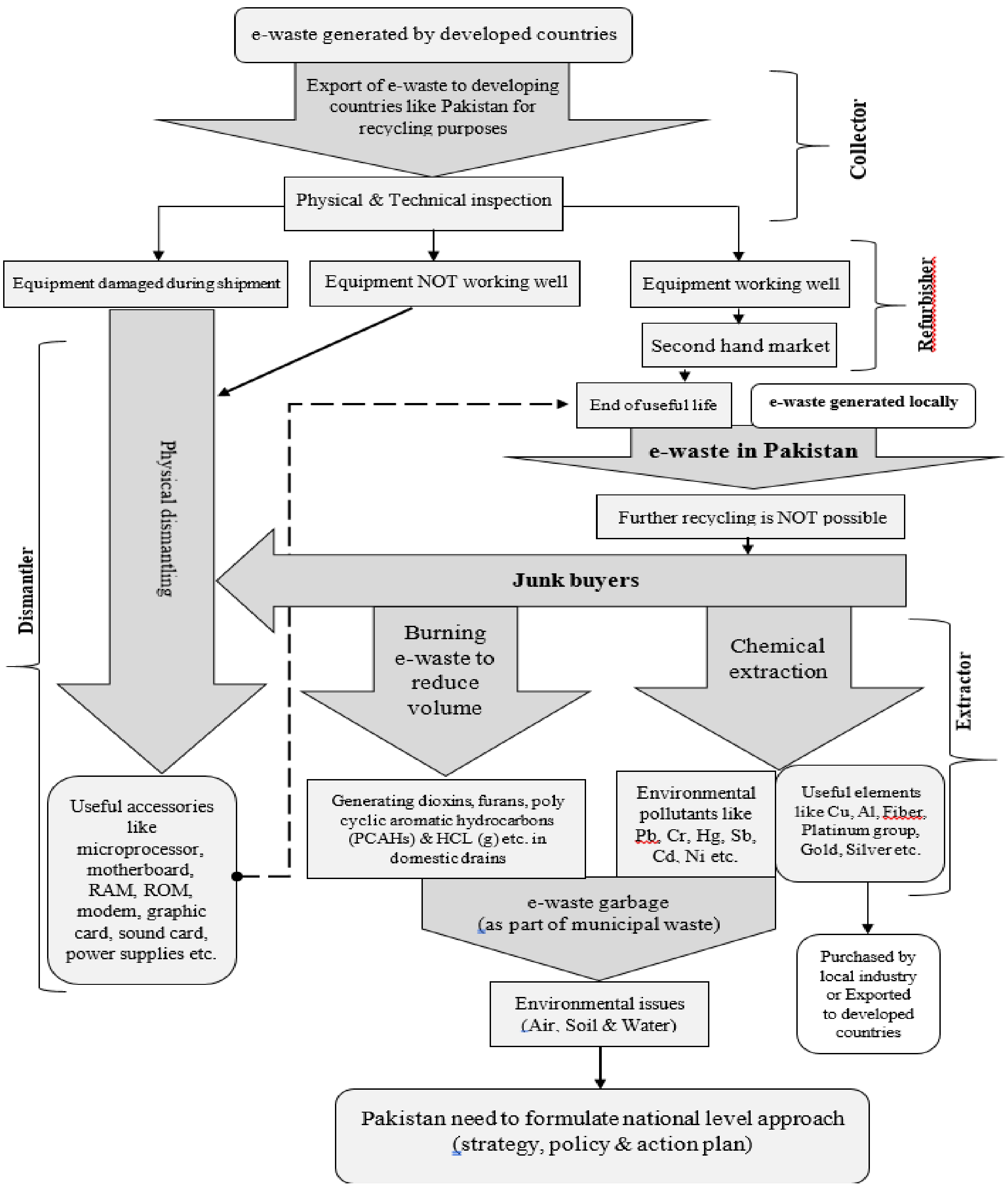

Figure 1: Schematic Diagram of e-Waste in Pakistan

Research Methodology and Scope of Study

This research limitations have two methods for research i.e. qualitative and quantitative research methods for phase-I and phase-II respectively as shown in Table 1. For first phase, consultation and focused interviews with experts are organized, whereas in second phase; questionnaires are distributed among e-waste industry located specifically in Rawalpindi and Lahore.

Table 1: Limitations of research study

S. No.	Method	Organization/Firm
1	Qualitative Research	Ministry of Climate Change, Islamabad
2		Ministry of Commerce, Islamabad
3		Pak Environmental Protection Agency, Islamabad
4		Ministry of Information Tech & Telecom, Islamabad
5		Sanitation Directorate, Metropolitan Corp. Islamabad
6		Environment Wing, Capital Development Authority, Isld.
7		Punjab Environmental Protection Deptt., Regional Office, Rwp.
8		Rawalpindi Development Authority, Rawalpindi
9		Rawalpindi Waste Management Company, Rawalpindi
10		Rawalpindi Cantonment Board, Rawalpindi
11		Punjab Environmental Protection Deptt., Lahore
12		Punjab Environmental Protection Agency, Lahore
13		Lahore Development Authority, Lahore
14		Lahore Waste Management Company, Lahore
15	Quantitative Research	E-waste market at Hafeez Centre, Lahore
16		E-waste market at Barkat Market, Lahore
17		E-waste market at Walton Road, Lahore
18		E-waste market at 6th Road, Rawalpindi
19		E-waste market at Saddar Bazar, Rawalpindi
20		E-waste market at DAV College Road, Rawalpindi

Survey tool design

Survey tool design i.e. a questionnaire for quantitative research method has total of 29 Likert scaled questions, which are synthesized by those 10 main factors (variables) discussed in research gap after the literature review and qualitative research analysis. Some of the questions are deliberately coded as negative/abnormal, so to identify outliers, if any.

Validity of survey

Internal validity of survey tool has two steps such as content validity (constructive feedback from experts) and reliability (validity criterion through Cronbach's alpha).

DATA COLLECTION AND RESULTS

Table 2: Sampling Frame for Qualitative Research Method

S. No.	Organization	No. of Interviews
1	MoCC, Islamabad	04
2	MoC, Islamabad	02
3	Pak-EPA, Islamabad	03
4	MoITT, Islamabad	02
5	MCI	03
6	CDA, Islamabad	04
7	Pb-EPD, Rwp Region	02
8	RDA, Rawalpindi	03
9	RWMC, Rawalpindi	04
10	RCB, Rawalpindi	01
11	Pb-EPD, Lahore	02
12	Pb-EPA, Lahore	06
13	LDA, Lahore	02
14	LWMC, Lahore	04
	Total	**42**

Table 3: Sampling Frame for Quantitative Research Method

S. No.	E-waste Industry	Distributed	Retrieved
1	Hafeez Centre, Lahore	247	61
2	Barkat Market, Lahore	23	9
3	Walton Road, Lahore	42	19
4	6th Road, Rawalpindi	227	56
5	Saddar, Rawalpindi	152	38
6	DAV College Road, Rawalpindi	54	13
7	Karachi	03	0
8	Others	144	1
	Total	**892**	**197**

Summary of Demographics for Quantitative Analysis

Gender

Table 4: Gender of Respondents

S. No.	Gender	No. of Respondents	%
1	Male	196	99.5
2	Female	01	0.5
	Total	**197**	**100**

Age (in years)

Table 5: Age of Respondents

S. No.	Age (in yrs)	No. of Respondents	%
1	≤15	25	35
2	16 to 25	15	21
3	26 to 35	20	28
4	36 to 45	10	14
5	> 45	1	2
	Total	**197**	**100**

Experience with e-Waste (in years)

Table 6: Respondents' Experience

S. No.	Exp (in yrs)	No. of Respondents	%
1	<1	10	5
2	1 to 5	61	31
3	6 to 10	74	38
4	11 to 20	47	24
5	> 20	5	2
	Total	**197**	**100**

Relationship with e-Waste

Table 7: Respondents' Relationship

S. No.	Relationship with e-Waste	No. of Respondents	%
1	Collector	14	7
2	Refurbisher	49	25
3	Dismantler	23	12
4	Extractor	4	2
5	Others	5	2
6	Collector & Refurbisher	40	20
7	Refurbisher & Dismantler	31	16
8	Dismantler & Extractor	18	9
9	Collector & Dismantler	7	4
10	Refurbisher & Extractor	0	0
11	Collector, Refurbisher & Dismantler	6	3
12	Refurbisher, Dismantler & Extractor	0	0
	Total	**197**	**100**

Distributions versus Retrievals rate

Table 8: Distributions vs. Retrievals rate of Respondents

S. No.	e-Waste Industry	Distributions		Retrievals	
		No.s	%	No.s	%
1	Hafeez Centre, Lahore	247	27.69	61	24.69
2	Barkat Market, Lahore	23	2.57	9	39.13
3	Walton Road, Lahore	42	4.70	19	45.23
4	6th Road, Rawalpindi	227	25.44	56	24.66
5	Saddar, Rawalpindi	152	17.04	38	25
6	DAV College Road, Rawalpindi	54	6.05	13	24.07
7	Karachi	03	0.33	0	0.00
8	Others	144	16.14	1	0.69
	Total	**892**	**100**	**197**	**22.10**

Sources adopted for collection of responses

Table 9: Sources adopted to get responses

S. No.	Questionnaire Sources	No. of Distributions	No. of Retrievals
1	By-hand	745	197
2	E-mail & google form	144	0
3	Postal Mail	3	0
	Total	**892**	**197**

Questionnaire Language

Table 10: Questionnaire language adopted by the industry

S. No.	Language	No. of Distributions	No. of Retrievals	%
1	Urdu	597	161	82
2	English	295	36	18
	Total	**892**	**197**	**100**

Exploratory Data Analysis (Box Plots)

During quantitative research method, the box plots are used when there may be an indication about variables having outlier(s), the ones who did not pay required attention while filling up the questionnaire, and took Liker-scaled questionnaire for granted, so harming the analysis.

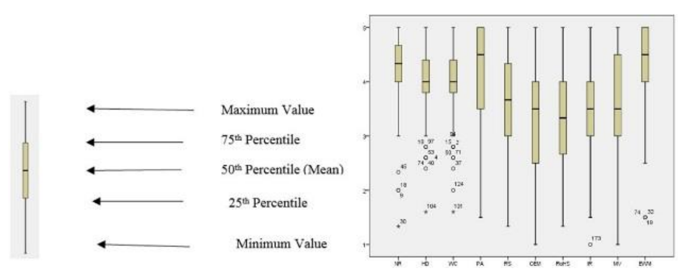

Figure 2: Box Plots of 197 responses (with outliers)

All the outliers shown in Figure 2 are positioned on the lower limits of all the variables (9 IVs and 1 DV). Steric (*) identify about a serious threat to the analysis, whereas a knot (Ϭ) means its negative effectiveness on the entire analysis. Hence, these outliers must be removed to have smooth data analysis after deleting all 7 outliers, leaving behind only 190 responses, as shown in Figure 3 below.

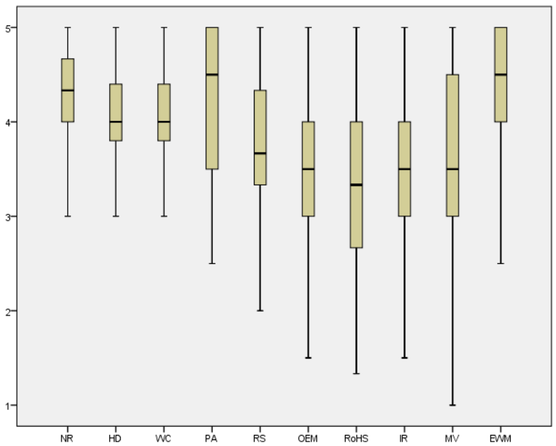

Figure 3: Box Plots of 190 responses (without outliers)

Data Analysis

Statistical Package for Social Sciences (SPSS) tool provides the reliability analysis (commonly called as Cronbach's Alpha) of variables showing significant level, which should be >0.60 to become acceptable for required results. Descriptive statistics & normality tests (such as skewness and kurtosis etc) are secured. Correlation analysis (Pearson's correlation) is used to see the strongness and weakness of correlation among variables in such a way that single steric (*) means strong correlation, and double steric (**) means very strong correlation between IVs and DV. Regression analysis is used to predict any unknown values through two or more variables, so this analysis evaluates Model Fitness assessment (R, R^2 and Adjusted R^2 etc.), analysis of variance (ANOVA), and Statistical Significance test (β value, and Correlations etc), and Collinearity diagnostics, as elaborated in Table 12. Two IVs i.e. WC and MV are eliminated here as they have very weak correlation with EWM so will not be considered any further, leaving behind only eight variables (seven IVs and a DV).

Collinearity diagnostics are used to see behaviour of the IVs with DV, whether they are reacting or not. Eigen values are shown in Table 11, which must never be approached to zero. But during the analysis here, it clearly ranges from 0.005 to 0.065 shows a serious threat to results. So, to have improved data analysis, Z-score values will be generated for all eight variables (seven IVs and a DV) which were shown strong correlation earlier.

Collinearity Diagnostics

This kind of diagnostics contains Eigen values which must never be ~0, and now improved by Z-score variables as ranges from 0.336 to 2.231 (earlier it was ranged from 0.005 to 0.065) as shown in Table 12. Condition Index are also improved as ranges from 1.000 to 2.576 (previously it was ranged from 9.517 to 33.379).

Table 11: Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (DV: EWM)					
				(Constant)	HD	PA	NR	OEM	IR
5	1	5.878	1.000	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.065	9.517	0.01	0.01	0.05	0.01	0.27	0.12
	3	0.025	15.437	0.00	0.00	0.09	0.06	0.47	0.66
	4	0.020	17.110	0.02	0.01	0.69	0.10	0.23	0.15
	5	0.007	28.197	0.14	0.36	0.17	0.77	0.02	0.05
	6	0.005	33.379	0.83	0.62	0.00	0.06	0.00	0.02

Table 12: Collinearity Diagnostics of Z-score variables

Model	Dimension	Eigen value	Condition Index	**Variance Proportions** (DV: EWM)					
				(Constt.)	Zscore: HD	Zscore: PA	Zscore: NR	Zscore: OEM	Zscore: IR
5	1	2.231	1.000	0.00	0.07	0.03	0.05	0.07	0.07
	2	1.000	1.493	1.00	0.00	0.00	0.00	0.00	0.00
	3	0.993	1.498	0.00	0.07	0.56	0.01	0.10	0.04
	4	0.891	1.582	0.00	0.03	0.06	0.66	0.04	0.08
	5	0.549	2.016	0.00	0.73	0.34	0.20	0.08	0.01
	6	0.336	2.576	0.00	0.09	0.00	0.08	0.72	0.80

Z-score values

Eight newly built Z-scored columns i.e. ZNR, ZHD, ZPA, ZRS, ZOEM, ZRoHS, ZIR and ZEWM are generated, whereas Assessment of Model Fitness, Statistical Significance Test, and Excluded variables will be treated as same as calculated earlier. But, Linear Regression Equation 2 will be needed slope (B) values as shown in Table 13.

Table 13: Coefficients for Regression Analysis of Z-score variables

Model (DV: EMW)		Unstandardized Coefficients		Standardized Coefficients
		B	**Std. Error**	**Beta**
5	(Constant)	4.363	0.029	
	Zscore: HD	0.342	0.035	0.558
	Zscore: PA	0.140	0.031	0.229
	Zscore: NR	0.121	0.032	0.198
	Zscore: OEM	-0.121	0.039	-0.198
	Zscore: IR	0.089	0.040	0.146

P-Plot and Partial Regression Plots

Expected versus Observed Cumulative Proportions provides Probability Plot, whereas if selected variable matches the test distribution, then points cluster must be around a linear straight line, as evident in Figure 4 below.

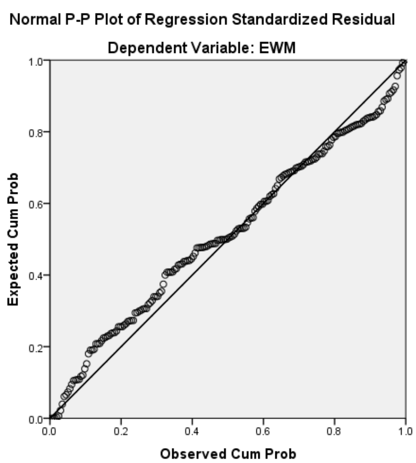

Figure 4: P-Plot of Regression Analysis for Z-values

Similarly, Partial Regression plots of all Z-scored IVs versus DV are in shape and well scattered.

Scatter Plot

Two responses i.e. no. 18 and 133 are positioned around 0.15 along x-axis as shown in Figure 5, are considerably problematic for the entire analysis. So, excluding both these two responses surprisingly directs the regression analysis to exclude another two IVs, hence leaving behind only three IVs in total. Therefore, it is decided by the researcher himself to remain them as they are.

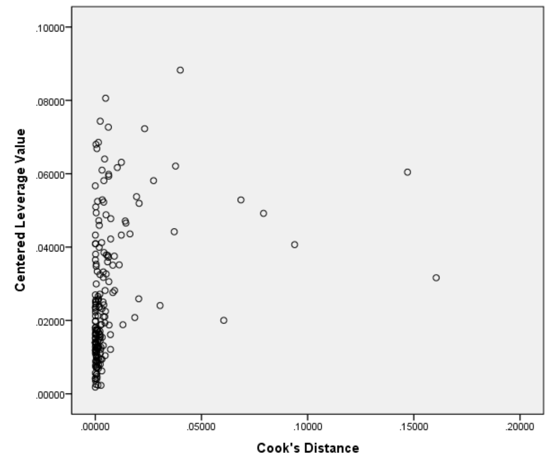

Figure 5: Cook's Distance vs. Centred Leverage Value

Linear Regression Equation (LRE)

Mathematically, this equation contains IV, DV and a slope. IVs, DV and slope are taken as Inputs 'x', Output 'y' and slope 'm' respectively, which all are already derived from B values of 5th Model as shown in Table 12.

Therefore

$$y = m_1x_1 + m_2x_2 + m_3x_3 + m_4x_4 + m_5x_5 + c \quad \ldots (1)$$

Hence, after putting all values we get

$$\Rightarrow EWM = 0.121NR + 0.342HD + 0.140PA + 0.089IR - 0.121OEM + 4.363 \quad \ldots (2)$$

Structural Equation Modelling (SEM)

Optimization technique is now adopted to verify analysis results, along with objective functions to be done by Equation 2. Table 14 shows initial results of Analysis of Moment Structures (AMOS) analysis.

Table 14: Results of Default Model

Chi-square	3.558
Degrees of freedom	3
Probability level	0.313

Modification Model indicated an error of -0.846, so summing up to 1.000 equals 0.154, then put this as E1 which will remove all errors in this model.

"Good model fit delivers an insignificant result at threshold of 0.05 [15]. Freedom Degree ratio must be ≥1, whereas Probability level for <300 samples must be >0.05 to be insignificant."

Step-by-step method would be adopted to get rid of highest problematic values to the lowest ones. Estimates show that EWM <-> ZWC has highest P value of 0.975 which should be

<0.05 (or ***) to be significant for regression weights, covariances, and variances.

Firstly, "remove ZWC (1st highest) connection, then ZRoHS (0.954) i.e. 2nd highest, and then to both ZRS and ZMV. Parent research model having all variables, and final research model after removing problematic variables along with interconnections is shown in Figure 6 above."

Later Root Mean-Square Residual (RMR) Index, Root Mean Square Error of Approximation (RMSEA) Index, Baseline Comparisons (NFI, RFI, IFI, TLI, and CFI) are done for finalizing the analysis. Standardized RMR value is 0.043 (must be ≤ 0.05) indicates a good fit. RMSEA index value is 0.031 indicates a convergence fit. Normed-Fit Index (NFI) values 0.990 (should be >0.90) which indicates a good fit, Reporting-Fit Indices (RFI) values0.950 also indicates a good fit. Incremental-Fit Indices (IFI) values 0.998 also indicates a good fit. Tucker-Lewis Index (TLI) values 0.992 also indicates a good fit, Comparative Fit Index (CFI) values 0.998 indicates a very good fit.

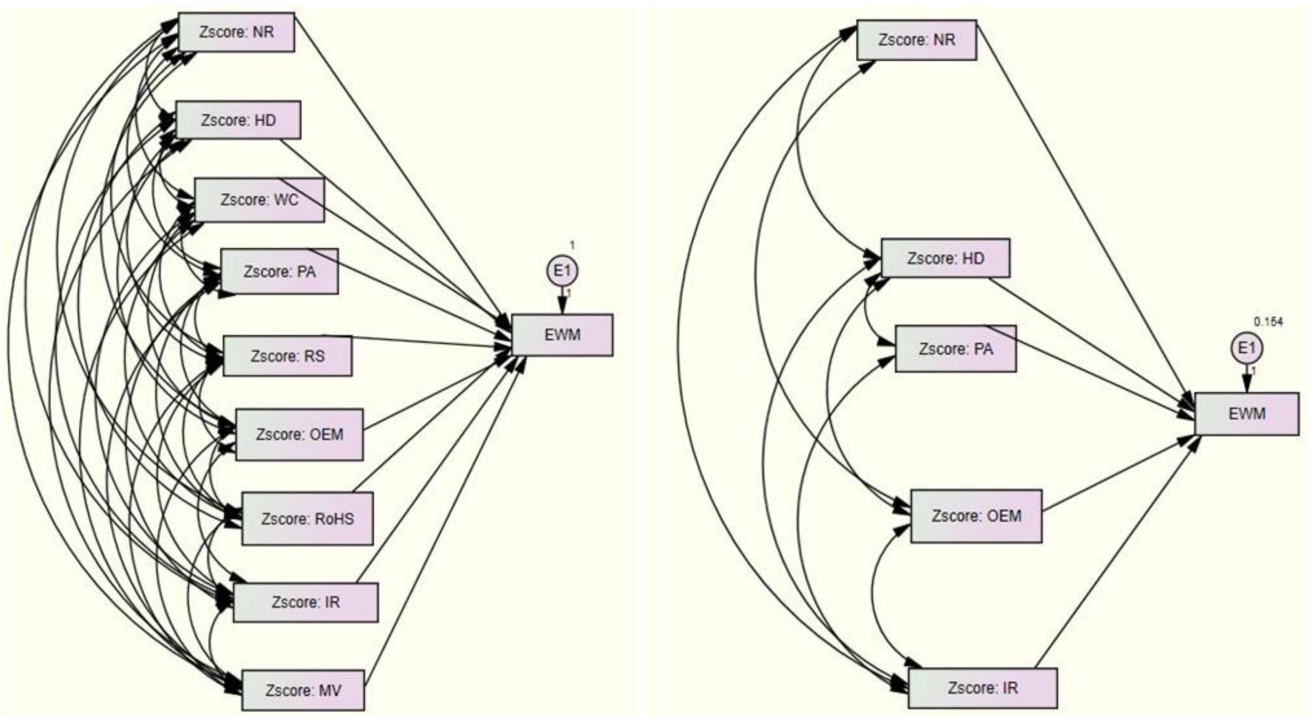

Figure 6: Parent and Final Research Model (Good Fit)

ANALYSIS AND DISCUSSIONS

Alternate hypotheses H_3, H_5, H_7, and H_9 are rejected whereas their null hypotheses are finally accepted, because these four could not achieve any significant/positive relationship with EWM, as shown in Table 15 below.

Table 15: Data Analysis Results

S. #	Var. Category	Variable Name	Reliability (Cronbach	Descriptive Statistics & Normality Test				χ^2	Correlation	Regression		Collinearity	Remarks
				μ	σ	Skewness	Kurtosis			R^2	Sig.		
1	**IV**	**NR**	**0.604**	**4.3561**	**0.53017**	**-0.544**	**-0.364**	**64.653**	**Very Strong**	**0.58**	**0.001**	**Not Collinear**	**Included**
2		**HD**	**0.611**	**4.0436**	**0.43396**	**-0.060**	**-0.550**	**74.926**	**Very Strong**		**0.000**	**Not Collinear**	**Included**

3		**WC**	**0.608**	**4.0326**	**0.43884**	**-0.323**	**-0.317**	**80.253**	**Very Weak**		**0.937**	**-**	**Excluded by Correlation**
4		**PA**	**0.686**	**4.2211**	**0.72087**	**-0.884**	**0.089**	**74.821**	**Very Strong**		**0.000**	**Not Collinear**	**Included**
5		**RS**	**0.670**	**3.6632**	**0.75825**	**-0.540**	**-0.448**	**59.579**	**Very Strong**		**0.780**	**Collinear**	**Excluded by Regression**
6		**OEM**	**0.631**	**3.3868**	**0.94789**	**-0.395**	**-0.511**	**45.032**	**Strong**		**0.021**	**Not Collinear**	**Included**
7		**RoHS**	**0.631**	**3.3333**	**0.81578**	**-0.252**	**-0.174**	**78.674**	**Very Strong**		**0.885**	**Collinear**	**Excluded by Regression**
8		**IR**	**0.620**	**3.5711**	**0.90790**	**-0.541**	**-0.060**	**71.895**	**Very Strong**		**0.043**	**Not Collinear**	**Included**
9		**MV**	**0.693**	**3.6921**	**0.95185**	**-0.601**	**-0.005**	**86.726**	**Very Weak**		**0.200**	**-**	**Excluded by Correlation**
10	**DV**	**EWM**	**0.628**	**4.3632**	**0.61266**	**-0.945**	**0.774**	**116.884**	**-**		**-**	**Not Collinear**	**Included**

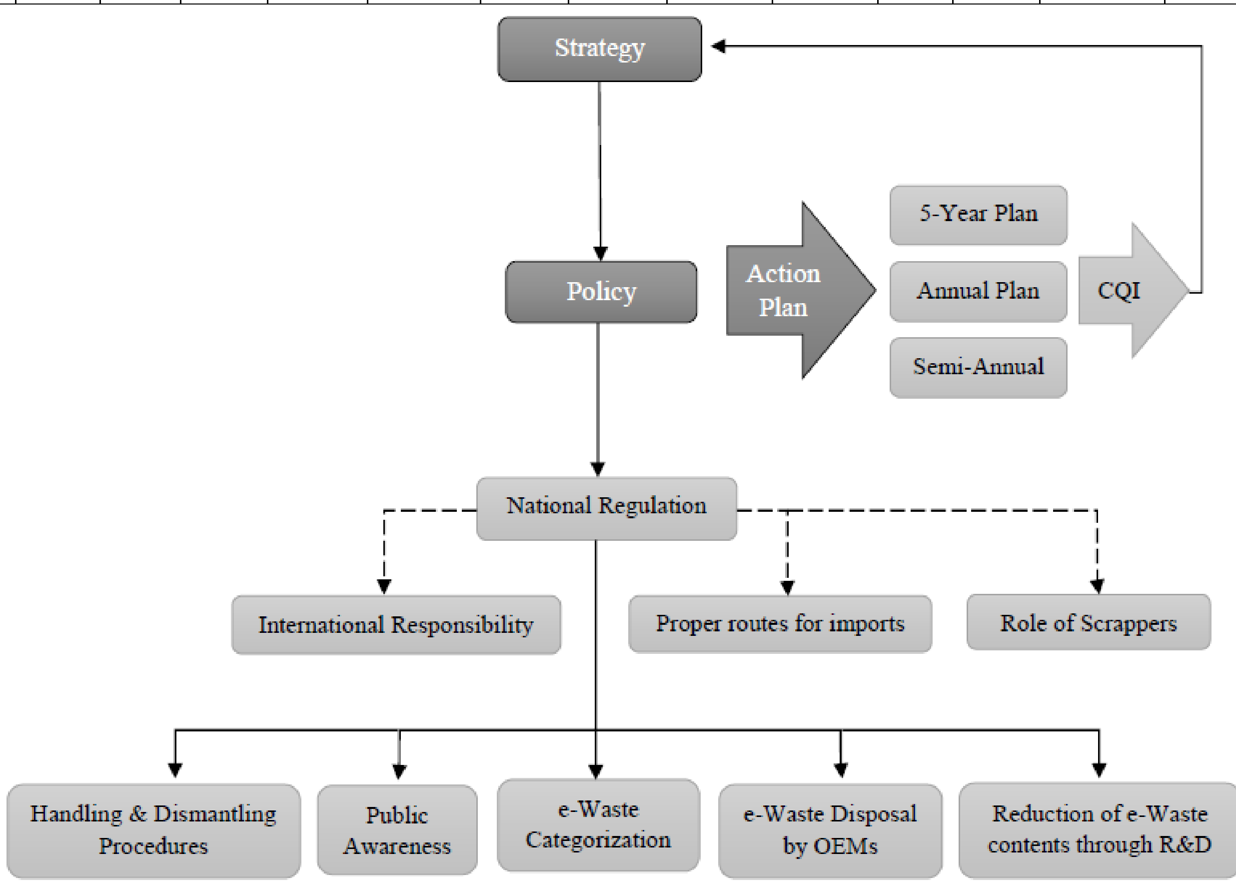

Figure 7: Approach Development for e-Waste Management

Hypothesis Results

Alternate hypothesis of WC is rejected but intentionally retained because labour working in municipal organizations are mostly uneducated/untrained, so lacks knowledge to categorize daily collected waste.

AH of RS is also deliberately preserved as labour lack in knowledge, and practicability, so did not understand e-waste toxicity. Respondents did not encourage their importance for 'Reverse Logistics' concept to send e-goods to their OEMs (having best understanding of their goods) for re-using their useful components.

Last but not at all least, AH of RoHS is also not accepted, but intentionally retained. EEE mostly are not developed in Pakistan. That is the reason why RoHS may not be dropped so retained to encourage Pakistani industry to somehow adopt the same RoHS concept by having innovations in their electronics manufacturing industry.

Table 16: Hypothesis Results

AH	IVs	DV	LRE	Acceptance / Rejection of AH
H1	NR	EWM	EWM=0.121NR+4.363	Accepted
H2	HD		EWM=0.342HD+4.363	Accepted
H3	WC		-	Rejected but retained
H4	PA		EWM=0.140PA+4.363	Accepted
H5	RS		-	Rejected but retained
H6	OEM		EWM=-0.121OEM+4.363	Accepted
H7	RoHS		-	Rejected but retained
H8	IR		EWM=0.089IR+4.363	Accepted
H9	MV		-	Rejected

Approach Development

Figure 7 shows the desired approach (strategy, policy and action plan) which will contribute in designing remedial measures to cope e-waste problem in Pakistan such as 5-year, annual or semi-annual plan, by adopting concept of Continuous Quality Improvement (CQI) towards Total Quality Management (TQM). The approach is designed to minimize the growth of e-waste in Pakistan, and it will be a gradual decrease, not a rapid one. Being technology follower, the country's economy is now dependent on e-waste import mainly due to its cheap price and easy to use.

Recommendations

- It is the need of time to design a national level approach by operational framework (see Section-4) like neighbouring countries like China (2007 policy) and India (2016 policy) has legislated
- Approach should be developed accordingly with male dominant labour in e-waste industry in Pakistan (see Table 4)
- Policy should be focusing child labour as they are found having breathing and skin issues specially in Walton road e-waste industry, Lahore. (see Table 6)
- Extractors must be located away from residential areas of metropolitan cities, as locals (residents) of Walton Road, Lahore are re-locating themselves by having visibly seen polluted area and facing asthma due to rapid increase in the e-waste industry there
- Curriculum at school level should also include e-waste management along with municipal waste management
- User manual of electronic products should have e-waste recycling section, so owner/user should also feel it as social responsibility
- Policy and action plan should be as per expectations of refurbishers majority (see Table 7)
- For maximum responses/retrievals, frequent follow-up visits should be organized (see Table 8)
- Manual distribution of questionnaires is recommended (see Table 9)
- Legislation to be notified and published in Urdu (see Table 10).

Conclusion

All results are taken after a thorough literature review, focused interviews with experts/gurus for qualitative analysis, and later field visits for quantitative analysis. These analysis directed to see what are the factors to cater the issue of e-waste in Pakistan, and to develop an action plan for effective disposal of e-waste in Pakistan by introducing handling and dismantling procedures at government level, public awareness through pamphlets and inclusion of e-waste in curriculum of schools, e-waste categorization at municipal level, safe disposal of e-waste by their OEMs having best understanding to re-use parts, and reducing the toxic materials in electronics manufacturing through R&D.

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