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# **Environmental governance and employment effects: An empirical research based on mediating effect model**

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**In recent years, the problem of large-scale production suspension of domestic enterprises and unemployment of laborers brought about by environmental governance is becoming increasingly serious. How to reduce the negative externalities of environmental governance has become an urgent practical problem that needs to be solved. Based on the Cobb-Douglas production function model, this paper introduced the mediating effect model with technological innovation as the intermediate variable to study the impact of environmental governance on employment. We chose Beijing-Tianjin-Hebei and surrounding areas with serious pollution as research objects, and used the panel data from 2005 to 2015 for empirical test. The results show that environmental governance has a positive effect on employment, and the high-intensity environmental governance will stimulate technological innovation, thereby stimulating employment growth. In the process of environmental governance, decision-making departments can not only effectively control environmental pollution by promoting technological innovation, but also reduce unemployment caused by environmental governance.**

**Key words:** Negative externalities of environmental governance, technological innovation, mediating effect model, employment.

## **INTRODUCTION**

There is a strong contrast between the people's yearning for a better life of ecological civilization and the increasingly serious environmental pollution caused by the industrial enterprises' pursuit of maximum profits at the expense of unconstrained high energy consumption. Environmental pollution has become a pain point affecting the national economy and people's livelihood. According to Greenpeace (2016), the most serious air pollution in 2016 has affected 460 million people, and its pollution level is six times that of the daily indicators of

the World Health Organization (<http://www.ftchinese.com/story/001070643?dailytop&archive>). In order to cope with the increasingly serious environmental problems, the Chinese government has gradually strengthened the control of environmental pollution and issued a series of pollution prevention and control policies. In addition, important strategic measures such as regional cooperation in pollution control should be taken to improve the ecological environment by drawing on the mature pollution control experience of

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developed countries such as Europe and the United States. The implementation of series of measures such as fog and haze weather stop production, VOCs charges, time-limited relocation and factory clearing has made certain achievements in the construction of environmental and ecological civilization. Environmental governance has achieved good results, environmental risks have been effectively controlled, the environmental governance has undergone qualitative change from cognition to practice, the total discharge of major pollutants has been greatly reduced, the intensity of pollution control has been gradually strengthened, and law enforcement supervision has been unprecedentedly strict. And the revision of the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution ([http://www.jingbian.gov.cn/info/contentView.jsp?info\\_id=62936&site\\_id=CMSjingbian](http://www.jingbian.gov.cn/info/contentView.jsp?info_id=62936&site_id=CMSjingbian)) and the promulgation of the *plan for the prevention and control of atmospheric pollution* (<http://www.jingbian.gov.cn/gk/zfwj/gwywj/41211.htm>) demonstrate the determination of the state to control air pollution with iron fist.

However, as mentioned by the Ministry of Environmental Protection of China (2017) that fighting the battle against environmental pollution was not only a systematic project, a livelihood project, but also related to the sustainable development of economy and social harmony and stability. Taking employment as an example, under the unprecedented strict environmental pollution control policy, many places have experienced the wave of enterprises to stop production, limit production, and close down, especially for small and medium-sized enterprises and energy-consuming enterprises. The unemployment tide of industrial workers has accompanied, and the employment panic has increased day by day, triggering a new round of social conflicts. Qin et al. (2018) has also pointed out that China is facing the challenge of "three phases superposition". The economic downturn, structural adjustment and digestion of excessive production capacity may cause very serious unemployment problems. As the basis of people's livelihood, employment is directly related to social harmony, stability, and a virtuous circle of national economic and social development. Therefore, under the national macro-environmental governance policy, how to explore more effective solutions to further improve the employment rate of skilled workers, enhance people's well-being, and promote the harmonious development of society has become a social problem that urgently needs to be solved. This paper took Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning and Shandong as the research objects. The data was selected from the relevant panel data of the seven provinces from 2005 to 2015 to study the relationship between environmental governance and employment. It also introduced technology innovation as an intermediate variable to explore the impact of negative externalities of

environmental governance on employment, which provided a reference for government decision-making departments to formulate differentiated governance policies for different regions.

## LITERATURE REVIEW

Through the scientific analysis of domestic and foreign research results, the relationship between environmental governance and employment in the theoretical community can be summarized into three aspects: positive impact, negative impact, and unclear impact. The first view is that environmental governance has a positive impact on employment. Morgenstern et al. (2002) found that in the four heavily polluting industries such as papermaking, plastics, gasoline smelting and steel, due to the strengthening of environmental governance, the polluting industry needs to put more labor into pollution control, thereby slowing down unemployment. Bezdek et al. (2008) found that environmental governance has a positive effect on employment, as new job opportunities such as environmental engineers and ecologists have been created through environmental protection. Similarly, domestic scholars have reached similar conclusions on this basis. Wang et al. (2013) found through theoretical research on production effects and demand effects that environmental governance would promote employment in industrial sectors when the intensity of environmental governance reached a certain threshold. Likewise, Li et al. (2014, 2015) found that there was a U-shaped relationship between environmental governance and employment. Yan et al. (2016) studied the impact of environmental governance on employment from the aspects of industrial structure, technological progress and FDI, and finally found that through the adjustment and improvement of industrial structure, environmental governance would indirectly promote the growth of employment. Thus it can be seen that the strengthening of environmental governance does not necessarily reduce the amount of employment.

The second view is that environmental governance has a negative impact on employment. Greenstone et al. (2002) used US corporate data to conduct empirical research and found that the implementation of the revised Clean Air Act would result in the loss of approximately 59,000 jobs in counties that did not meet the standards. Dissou and Sun (2013) used the general equilibrium theory model to assess the impact of carbon reduction policies on employment, found that this policy would have adverse effects on employment and livelihood. Fan and Mu (2017) used the panel threshold model and applied the employment data of laborers in 30 provinces (cities) in China to conduct empirical analysis. They found that the increase of environmental governance intensity was the most disadvantageous for migrant workers. Sun and Yang (2017) used the double

difference method to analyze the relationship between the “two control zones” policy and employment, and found that the implementation of the “two control zones” policy was not conducive to the improvement of the overall employment level of the city. (The “two control zones” policy belongs to a means of environmental governance and is an exclusive term in the field of environmental protection. It refers to the abbreviation of acid rain control zone or SO<sub>2</sub> pollution control zone. The *Law of Prevention and Control of Atmospheric Pollution* stipulates that according to natural conditions such as meteorology, topography and soil, areas where acid rain has occurred or where other SO<sub>2</sub> pollution is serious may be classified as acid rain control zone or SO<sub>2</sub> pollution control zone, that is “Two control zones”).

The third view is that the impact of environmental governance on employment is uncertain. Walker et al. (2011) believed that the impact of environmental governance on employment was actually the redistribution of employment between industries, rather than the level of employment across the economy. Shimer (2013) found through empirical research that the uncertainty of the impact of environmental governance on employment mainly came from the substitution effect between labor and pollutant emissions. Because the substitution rate of these two factors in different industries was different, the final total effect was also uncertain. Liu et al. (2018) found that there is a U-shaped relationship between environmental regulation and individual employment probability, and the impact of environmental regulation on employment of workers in different regions, industries and household registration is different. Li et al. (2016) used the panel model to study the relationship between environmental governance and employment, and found that their relationship was a nonlinear U-shaped relationship, which had some uncertainty on the impact of employment.

Although there are differences between the three viewpoints, they all believed that environmental governance had a non-negligible effect on employment. Based on this, this paper firstly combined the C-D production function and the mediating effect model based on the existing research on environmental governance and employment relationship, aiming to study the impact of environmental governance on employment by constructing the path of environmental governance-technological innovation-employment. Secondly, using the investment in pollutants control and SO<sub>2</sub> removal as the indicators of environmental governance, this paper studied how environmental governance affects employment through technological innovation under these two indicators. Finally, the related robustness tests of OLS, FE, 2SLS and GMM were used to test the relationship between variables and employment. This again demonstrates that the impact of environmental governance on employment can be mitigated by strengthening technological innovation.

## RESEARCH DESIGN

### Parameters and variables

Table 1 summarizes the parameters and variables used in the model. Table 1 mainly includes dependent variable, independent variable and control variables, which are explained as follows:

**Dependent variable:** The dependent variable  $L_{it}$  is the total employment of province  $i$  in each year. The core independent variable is environmental governance, which is expressed by the investment in pollutants control  $EN_{it}$  and SO<sub>2</sub> removal  $P_{it}$  in each region, respectively.

**Intermediary variable:** technological innovation  $A_{it}$ , which is expressed the number of patent applications authorized in each province.

**Control variables:**  $K_{it}$  is the capital stock of each province, which is expressed by the annual net value of fixed assets in each province.  $GDP_{it}$  is the level of regional economic development, which is expressed by the actual GDP of each province in China.  $W_{it}$  is the regional wage level, which is expressed by the average wage level in each province.  $IS_{it}$  is the regional industrial structure, which is expressed by the ratio of the tertiary industrial output value of each province to the actual GDP of each province.

### Model developed

This paper referred to the methods of Bohringer et al. (2012) and Gan et al. (2015) and Jiang (2017), and assumed that the production function is a Cobb-Douglas function, namely:  $Y = AL^\alpha K^\beta$ . On this basis, environmental governance is used as a factor input. Labor input, technological innovation, capital stock, economic development level, wage level and industrial structure are taken as output of production, and these factors are incorporated into the production function model. Let  $EN_{it}$  be environmental governance;  $A_{it}$  be the level of technological innovation of region  $i$  at time  $t$ .  $K_{it}$  is the capital input of region  $i$  at time  $t$ ;  $L_{it}$  is the labor input of region  $i$  at time  $t$ ;  $GDP_{it}$  is the level of regional economic development;  $W_{it}$  is the level of wages;  $IS_{it}$  is the regional industrial structure. Therefore, the modified Cobb-Douglas production function on the relationship between environmental governance and employment is shown in Equation 1:

$$Y_{it} = A_{it}^{\alpha_1} K_{it}^{\alpha_2} L_{it}^{\alpha_3} EN_{it}^{\alpha_4} W_{it}^{\alpha_5} IS_{it}^{\alpha_6} \quad (1)$$

In the Equation 1,  $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6$  are all parameters greater than 0 and less than 1. Then take the natural logarithm on both sides of the production function to get the Equation 2.

$$\ln Y_{it} = \alpha_1 \cdot \ln A_{it} + \alpha_2 \cdot \ln K_{it} + \alpha_3 \cdot \ln L_{it} + \alpha_4 \cdot \ln EN_{it} + \alpha_5 \cdot \ln W_{it} + \alpha_6 \cdot \ln IS_{it} \quad (2)$$

Among them,

$$\beta_1 = -\frac{\alpha_1}{\alpha_3}, \beta_2 = -\frac{\alpha_2}{\alpha_3}, \beta_3 = -\frac{\alpha_4}{\alpha_3}, \beta_4 = -\frac{\alpha_5}{\alpha_3}, \beta_5 = -\frac{\alpha_6}{\alpha_3}, \beta_6 = \frac{1}{\alpha_3},$$

**Table 1.** Parameter and variable definitions.

Parameter and variable	Definition	Units
$\alpha_1$ to $\alpha_6$	coefficients of elasticity for the production input factors in equation 1	Dimensionless
$A_{it}$	The technology level of province $i$ in $t$ year, which we represented by the number of authorized domestic patent applications	Number
$\beta_1$ to $\beta_6$	Fitting parameters for equation 3	Dimensionless
$EN_{it}$	Pollution control annual investment of province $i$ in $t$ year	RMB
$GDP_{it}$	Gross domestic product of province $i$ in $t$ year	RMB
$IS_{it}$	Industrial structure of province $i$ in $t$ year	-
$K_{it}$	The net value of fixed assets in province $i$ in $t$ year	RMB
$L_{it}$	The employment in province $i$ in $t$ year	Persons
$P_{it}$	Annual removal of SO <sub>2</sub> in province $i$ in $t$ year	t/year
$W_{it}$	Average wage level of province $i$ in $t$ year	RMB

and  $Y_{it} = GDP_{it}$ . Therefore, a regression equation concerning environmental governance and employment is obtained, as shown

$$\ln L_{it} = \beta_0 + \beta_1 \cdot \ln A_{it} + \beta_2 \cdot \ln K_{it} + \beta_3 \cdot \ln EN_{it} + \beta_4 \cdot \ln GDP_{it} + \beta_5 \cdot \ln W_{it} + \beta_6 \cdot \ln IS_{it} + \varepsilon_{it} \tag{3}$$

Where,  $\varepsilon_{it}$  is a random disturbance term.

To further study the impact of environmental governance on employment. This paper mainly referred to the mediating effect test method of Wen et al. (2004), and on the basis of Equation 3, to rebuild it. Thus, a mediating effect model based on technological innovation as mediator variable was constructed, as shown in Equation 4:

$$\begin{cases} \ln L_{it} = C + \alpha \ln EN_{it} + \beta_1 \ln W_{it} + \beta_2 \ln IS_{it} + \mu_{1it} \\ \ln A_{it} = C + \beta \ln EN_{it} + \mu_{2it} \\ \ln L_{it} = C + \alpha' \ln EN_{it} + \gamma \ln A_{it} + \beta_2 \ln IS_{it} + \mu_{3it} \end{cases} \tag{4}$$

Where, the mediating effect is determined by the coefficient of the second equation  $\beta$  and the third equation  $\gamma$  in Equation 4. If  $\beta$  is significant,  $\gamma$  is also significant, and the coefficient  $\alpha'$  in the third equation is also significant, then the mediating effect is significant. If the environmental governance coefficient  $\alpha'$  in the third equation is not significant, there is a complete mediating effect, if significant, it is a part of the mediating effect. Among them, the mediating effect is represented by  $\beta * \gamma$ , and the total effect is:  $\beta * \gamma + \alpha'$ , and the

Sobel statistic is:  $Z = \beta \cdot \gamma / S_{\beta \cdot \gamma}$ ,  $S_{\beta \cdot \gamma} = \sqrt{\beta^2 \cdot S_{\gamma}^2 + \gamma^2 \cdot S_{\beta}^2}$ , then the mediating effect test procedure diagram is shown in Figure 1.

**Sample selection and data source**

This paper mainly selected seven provinces in Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning and Shandong with serious pollution as empirical objects. The data selection interval is

in Equation 3:

the panel data of the seven provinces from 2005 to 2015, with a total of 4312 samples. These data come from China Environmental Statistics Yearbook (<http://tongji.cnki.net/kns55/Nav/HomePage.aspx?id=N2018050254&name=YHJSD&floor=1>), China Industrial Economics Statistical Yearbook (<http://tongji.cnki.net/kns55/Nav/HomePage.aspx?id=N2017120292&name=YZGJN&floor=1>), China Labor Statistics Yearbook (<http://tongji.cnki.net/kns55/Nav/HomePage.aspx?id=N2018070151&name=YZLDT&floor=1>), China Statistical Yearbook (<http://tongji.cnki.net/kns55/Nav/HomePage.aspx?id=N2017100312&name=YINFN&floor=1>), China Science and Technology Statistical Yearbook (<http://tongji.cnki.net/kns55/Nav/HomePage.aspx?id=N2018050248&name=YBVCX&floor=1>), and China's economic and social development statistics database (<http://tongji.cnki.net/kns55/>), respectively. Statistical analysis was performed using spss19.0 and stata14.0 software.

**EMPIRICAL ANALYSIS**

**Descriptive statistics and correlation analysis of variables**

Before conducting the mediating effect test, the basic descriptive statistical analysis and correlation analysis were performed on each variable. The analysis results are shown in Table 2.

Table 2 shows the descriptive statistical result of each variable. There are mainly eight research variables and the number of samples for each variable is 77, respectively. What's more, there is a great difference

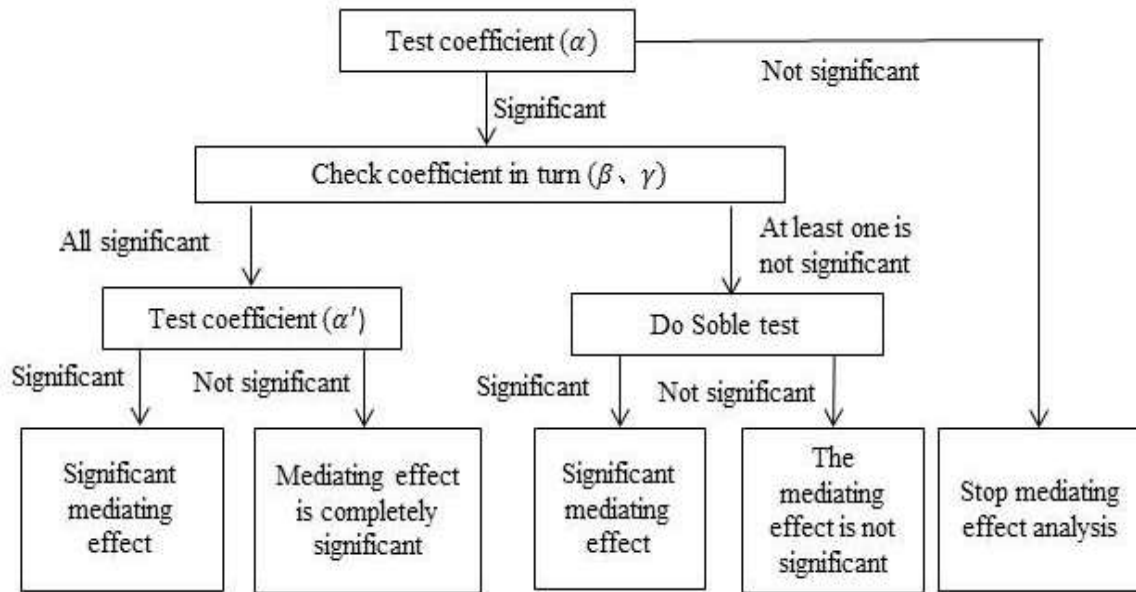


Figure 1. Test procedure diagram of mediating effect.

Table 2. Descriptive statistics of main variables.

Variable name	Minimum values	Maximum values	Average values	Standard deviations
$\ln L$	5.515	7.670	6.629	0.536
$\ln A$	6.739	11.494	9.261	1.195
$\ln K$	6.572	10.103	8.258	0.796
$\ln GDP$	8.268	11.051	9.574	0.660
$\ln EN$	3.709	6.743	5.437	0.723
$\ln P$	1.437	15.583	9.645	5.440
$\ln W$	0.378	2.426	1.322	0.483
$\ln IS$	-1.139	-0.223	-0.866	0.255

$\ln L$  is the natural logarithm of the total annual employment;  $\ln A$  is the natural logarithm of the technology level;  $\ln K$  is the natural logarithm of the net value of fixed assets;  $\ln GDP$  is the natural logarithm of the gross domestic product;  $\ln EN$  is the natural logarithm of pollution control investment;  $\ln P$  is the natural logarithm of annual removal of  $SO_2$ ;  $\ln W$  is the natural logarithm of average wage level;  $\ln IS$  is the natural logarithm of industrial structure.

between the maximum value and the minimum value of each variable, And the average value level is higher, indicating a higher degree of dispersion between variables. Among them, the coefficient of variation of environmental governance is 0.13. However, the statistical characteristics of the main variables do not fully reflect the relationship between environmental governance and employment. To this end, the Pearson correlation test was carried out for each variable in this paper. The test results are shown in Table 3.

From Table 3, it can be found that there is a positive correlation between investment in environmental governance  $EN$  and the employment  $L$ , and the

correlation coefficient is 0.764, which is significant at the 1% confidence level. When environmental governance is measured by  $SO_2$  removal, it is also positively correlated with employment. The correlation coefficient is 0.257, and it is significant at 5% confidence level. This indicates that there is a positive correlation between environmental governance and employment in Beijing-Tianjin-Hebei and surrounding areas. In addition, technological innovation, capital stock and economic development level are also positively correlated with employment, which are significant at the 1% confidence level. Although the wage level and regional industrial structure are positively correlated with employment, they are not significant. It

**Table 3.** Pearson correlation coefficient matrix between variables.

	$\ln L$	$\ln A$	$\ln K$	$\ln GDP$	$\ln EN$	$\ln P$	$\ln W$	$\ln IS$
$\ln L$	1							
$\ln A$	0.734**	1						
$\ln K$	0.754**	0.643**	1					
$\ln GDP$	0.859**	0.785**	0.898**	1				
$\ln EN$	0.764**	0.626**	0.741**	0.898**	1			
$\ln P$	0.257*	-0.213	0.343**	0.209	0.275*	1		
$\ln W$	0.214	0.646**	0.171	0.429**	0.493**	-0.327**	1	
$\ln IS$	0.131	0.484**	-0.282*	0.012	0.045	-0.563**	0.689**	1

$\ln L$  is the natural logarithm of the total annual employment;  $\ln A$  is the natural logarithm of the technology level;  $\ln K$  is the natural logarithm of the net value of fixed assets;  $\ln GDP$  is the natural logarithm of the gross domestic product;  $\ln EN$  is the natural logarithm of pollution control investment;  $\ln P$  is the natural logarithm of annual removal of  $SO_2$ ;  $\ln W$  is the natural logarithm of average wage level;  $\ln IS$  is the natural logarithm of industrial structure. The correlation coefficient between variables is Pearson correlation coefficient matrix, the significance test of correlation coefficient of pairing coefficient is two-sided test; \*\*indicates significant correlation at 1% bilateral confidence level, \*indicates a significant correlation at the 5% bilateral confidence level.

can be seen from the basic Pearson test results that there is a positive correlation between environmental governance and employment in each province of Beijing-Tianjin-Hebei and surrounding areas.

### The impact of environmental governance on employment

In order to further study the impact of environmental governance on employment, this paper took the pollutant control investment  $EN$  and  $SO_2$  removal  $P$  as the measurement variables of environmental governance. SPSS19.0 software was used to test their relationship with employment, respectively (Table 4).

The regression results of the first column of environmental governance and employment in Table 4 show that there is a significant positive correlation between environmental governance and employment at the level of 1%. The correlation coefficient is 0.567. After adding the mediating variable of technological innovation in the second column, the relationship between environmental governance  $EN$  and employment  $L$  is still significantly positive correlation, and the correlation coefficient is 0.201. After adding the variables such as capital stock, wage level, economic growth level and industrial structure in the third column, there is still a positive correlation between environmental governance and employment. The correlation coefficient is 0.269, which is significant at 1% confidence level. Similarly, the results in columns (4)-(6) of Table 4 show that environmental governance with  $SO_2$  removal as a measurement of indicators, whether it is a univariate regression, or a regression between median variables or other explanatory variables and employment. There is a positive correlation between environmental governance

and employment, and they are significant at the 1 and 5% confidence levels, respectively. The test results show that whether it is the pollution control investment as the measurement variable of environmental governance, or the  $SO_2$  removal as the measurement variable of environmental governance, environmental governance has always been positively correlated with employment.

### Analysis of the mediating effect of environmental governance on employment through introducing technological innovation

After a series of analysis and testing of each variable, it is found that environmental governance has a positive effect on employment. On this basis, this paper introduced technological innovation as a mediating variable, and the investment amount of pollutant control and  $SO_2$  removal were taken as the measurement indicators of environmental governance, respectively. To study how environmental governance stimulates technological innovation to reduce the negative externalities of environmental governance. We first examined technological innovation as a mediating variable to mitigate the impact of negative externalities of environmental governance on employment. The results are shown in Table 5. Step 1: Take the employment as dependent variable and environmental governance as independent variable, and carry out regression analysis on it. Step 2: Regression analysis was carried out again with technological innovation as dependent variable and environmental governance as independent variable. Step 3: Regression with the employment as the dependent variable, technological innovation and environmental governance as independent variables, and the control variables were added to each regression equation. Firstly,

**Table 4.** Analysis of the direct impact of environmental governance on employment.

	(1)	(2)	(3)	(4)	(5)	(6)
C	3.547*** (0.303)	2.270*** (0.255)	1.309*** (0.452)	6.385*** (0.122)	2.359*** (0.344)	0.384 (0.309)
$\ln EN$	0.567*** (0.055)	0.201*** (0.058)	0.269*** (0.068)			
$\ln P$				0.025** (0.011)	0.032*** (0.008)	0.021*** (0.004)
$\ln A$		0.151*** (0.038)	0.021 0.049		0.297*** (0.044)	0.026 (0.045)
$\ln K$		0.191*** (0.066)	0.153* (0.080)		0.147** (0.069)	0.046 (0.077)
$\ln W$			-0.837*** (0.063)			-0.725*** (0.056)
$\ln GDP$			0.493*** (0.125)			0.795*** (0.076)
$\ln IS$			1.402*** (0.184)			1.423*** (0.172)
Obs.	77	77	77	77	77	77
Adj.R <sup>2</sup>	0.579	0.712	0.925	0.053	0.722	0.933

$\ln A$  is the natural logarithm of the technology level;  $\ln K$  is the natural logarithm of the net value of fixed assets;  $\ln GDP$  is the natural logarithm of the gross domestic product;  $\ln EN$  is the natural logarithm of pollution control investment;  $\ln P$  is the natural logarithm of annual removal of SO<sub>2</sub>;  $\ln W$  is the natural logarithm of average wage level;  $\ln IS$  is the natural logarithm of industrial structure.

Note: \*\*\*, \*\*, and \* indicate significant at the confidence level of 1, 5 and 10%, respectively.

the environmental governance coefficient in step 1 was tested, and if the result was significant, proceeding to step 2, otherwise the test was terminated. As can be seen from Table 4, the regression coefficient of environmental governance is 0.813, and it is significant at the 1% confidence level. Therefore, the second step and the third step can be performed. If the regression coefficient of environmental governance in the second step and the regression coefficient of technological innovation in the third step are significant, the mediating effect is significant. As shown in Table 5, the two coefficients of environmental governance are 1.035 and 0.266, respectively, which are all significant at the 1% confidence level. Therefore, environmental governance has a significant impact on employment through prompting technological innovation. The results are shown in Table 5.

From the regression results of Panel A in Table 4, it can be seen that each province in the Beijing-Tianjin-Hebei and surrounding areas would mitigate the impact of

negative externalities of environmental governance on employment by strengthening technological innovation as a means of regulation. Among them, environmental governance plays a positive role in promoting technological innovation. Moreover, by strengthening technological innovation capabilities, it can effectively mitigate the impact of the negative externalities of environmental governance on employment. Under the storm of high-intensity environmental governance, if enterprises want to survive and meet the emission targets set by the state, they must reduce the emission of pollutants by increasing scientific and technological research and development, strengthening investment in technological innovation, and introducing technological talents. To a certain extent, this has created jobs with high technical content, thereby alleviating the adverse effects of environmental governance on the employment of workers. The Z statistic in the Sobel test is 2.1209, which is more than the critical value at the 5% significance level. Therefore, there exists a mediating

**Table 5.** The mediating effect of environmental governance on employment through technological innovation.

Dependent variable/ Independent variables	Panel A: $EN$			Panel B: $P$		
	Step1: $\ln L$	Step2: $\ln A$	Step3: $\ln L$	Step1: $\ln L$	Step2: $\ln A$	Step3: $\ln L$
$C$	4.334*** (0.274)	3.636*** (0.816)	2.877*** (0.232)	6.407*** (0.444)	9.712*** (0.274)	2.938*** (0.337)
$\ln EN_{it}$	0.813*** (0.055)	1.035*** (0.149)	0.569*** (0.044)			
$\ln P_{it}$				0.046*** (0.013)	-0.047* (0.025)	0.043*** (0.007)
$\ln A_{it}$			0.266*** (0.027)			0.453*** (0.032)
$\ln W_{it}$	-0.807*** (0.114)		-0.876*** (0.075)	0.202 (0.162)		-0.460*** (0.096)
$\ln IS_{it}$	1.223*** (0.188)		0.742*** (0.133)	0.565 (0.350)		0.359** (0.182)
Obs.	77	77	77	77	77	77
Adj.R <sup>2</sup>	0.749	0.384	0.892	0.161	0.033	0.774
Sobel test	Z=2.1209, The mediating effect is significant			Z=-0.2393, The mediating effect is not significant		
Mediating effect	Mediating effect =0.2753			Mediating effect =-0.0213		
Total effect	Total effect =0.8443			Total effect =0.0217		
	Mediating effect / Total effect =32.61%			Mediating effect / Total effect =-98.08%		

$\ln L$  is the natural logarithm of the total annual employment;  $\ln A$  is the natural logarithm of the technology level;  $\ln EN_{it}$  is the natural logarithm of pollution control investment;  $\ln P_{it}$  is the natural logarithm of annual removal of  $SO_2$ ;  $\ln W_{it}$  is the natural logarithm of average wage level;  $\ln IS_{it}$  is the natural logarithm of industrial structure.

Note: \*, \*\*, \*\*\* indicate significant at the confidence level of 10, 5, and 1%, respectively.

effect with technological innovation as a mediating variable. The mediating effect accounts for 32.61% of the total effect, indicating that technological innovation is conducive to mitigating the adverse impact of environmental governance on employment. Similarly, the regression results of Panel B show that in the impact of environmental governance on employment, there is also a mediating effect of technological innovation as a mediating variable. However, it can be found that in the process of environmental governance,  $SO_2$  removal is taken as a measurement index, and environmental governance is inversely proportional to input in technological innovation. The main reason is that with the strengthening of environmental governance, the amount of pollutants removed in each province of Beijing, Tianjin

and Hebei and surrounding areas is also increasing. Nevertheless, the technical input and technological innovation capabilities of various provinces are limited. The investment of decontamination equipment is also small, which shows the importance of technological innovation in environmental governance. From the third step in Panel B, it can be found that environmental governance has promoted employment after adding technological innovation variable. It can be seen that, although the measurement indicators of environmental governance are different, environmental protection can not only reduce environmental pollution, but also alleviate the problem of unemployment tide in local areas caused by the negative externalities of "one-size-fits-all" environmental governance.



**Table 6.** Robust test of the impact of environmental governance on employment.

Independent variables	Panel OLS		FE		2SLS		GMM	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	<i>EN</i>	<i>P</i>	<i>EN</i>	<i>P</i>	<i>EN</i>	<i>P</i>	<i>EN</i>	<i>P</i>
$\ln EN$	0.269*** (0.677)		0.055 (0.033)		0.269*** (0.068)		0.269*** (0.068)	
$\ln P$		0.021*** (0.004)		-0.070** (0.026)		0.021*** (0.004)		0.021*** (0.004)
$\ln A$	0.021 (0.049)	0.026 (0.045)	0.069 (0.061)	0.054 (0.065)	0.021 (0.047)	0.026 (0.043)	0.021 (0.047)	0.026 (0.043)
$\ln K$	0.153* (0.080)	0.046 (0.074)	0.056 (0.087)	0.115 (0.077)	0.153** (0.066)	0.046 (0.070)	0.153** (0.066)	0.046 (0.071)
$\ln GDP$	0.493*** (0.125)	0.795*** (0.075)	0.193 (0.107)	0.298*** (0.078)	0.493*** (0.124)	0.795*** (0.072)	0.493*** (0.124)	0.795*** (0.072)
$\ln W$	-0.837*** (0.063)	-0.725*** (0.055)	-0.018 (0.130)	-0.011 (0.111)	-0.837*** (0.061)	-0.725*** (0.053)	-0.837*** (0.061)	-0.725*** (0.053)
$\ln IS$	1.402*** (0.183)	1.423*** (0.158)	0.257** (0.099)	0.235** (0.086)	1.402*** (0.166)	1.423*** (0.150)	1.402*** (0.166)	1.423*** (0.150)
Cons	1.309*** (0.452)	0.384 (0.257)	3.624*** (0.901)	3.216*** (0.700)	1.309*** (0.443)	0.384 (0.245)	1.309*** (0.443)	0.384 (0.245)
Obs.	77	77	77	77	77	77	77	77

$\ln A$  is the natural logarithm of the technology level;  $\ln K$  is the natural logarithm of the net value of fixed assets;  $\ln GDP$  is the natural logarithm of the gross domestic product;  $\ln EN$  is the natural logarithm of pollution control investment;  $\ln P$  is the natural logarithm of annual removal of  $SO_2$ ;  $\ln W$  is the natural logarithm of average wage level;  $\ln IS$  is the natural logarithm of industrial structure.

Note: \*, \*\*, \*\*\* indicate significant at levels of confidence of 10, 5, and 1%, respectively.

## Robust test

In order to ensure that the regression results are not affected by measurement indicators of environmental governance and control variables. In this paper, the statistical methods such as ordinary least squares estimation (OLS), FE test, 2SLS and GMM test were used to test the impact of environmental governance on employment. The results are shown in Table 6. From Table 6, we can find that in OLS test, 2SLS and GMM test, whether environmental governance is based on the investment in pollutant control or  $SO_2$  removal as a measurement indicator, there is a positive correlation between environmental governance and employment, and it is significant at 1% confidence level. Similarly, the mediator of technological innovation is also positively correlated with employment, which again validates the conclusions in Table 4. By introducing technological innovation, it is possible to reduce the impact of negative externalities of environmental governance on

employment. The results in Table 5 also show that the industrial structure, regional economic development level, capital structure and so on are positively related to employment. The impact of environmental governance on employment may also be affected by many factors such as regional economic development. Therefore, under the storm of environmental governance, the intensity, mode and path of environmental governance should consider the differences of various regions and implement differential environmental governance policies.

From the above empirical results, it can be found that whether the investment of pollution governance or  $SO_2$  removal is used as a measure of environmental governance, there is a positive correlation between environmental governance and employment, indicating that effective environmental governance can play a positive role in promoting employment. At the same time, after introducing the intermediary variable of technological innovation, it can be found that the re-employment of skilled workers can be promoted by

strengthening the intensity of technological innovation. This also alleviates the adverse effects of high-intensity environmental governance on employment to a certain extent. This is consistent with the conclusion reached by Morgenstern (2002), indicating that although the intensity of environmental governance has increased, as long as an effective solution can be found, a win-win situation between the mitigation of environmental governance negative externalities and employment growth can still be achieved.

## CONCLUSIONS AND POLICY RECOMMENDATION

This paper used the panel data of the relevant variables in seven provinces of Beijing-Tianjin-Hebei and surrounding areas from 2005 to 2015. Based on the Cobb-Douglas production function, a mediating effect model with technological innovation as a mediating variable was introduced. And this paper empirically analyzed the impact of negative externality of environmental governance on employment, which is measured by investment in pollutant control and industrial SO<sub>2</sub> removal. The results show that environmental governance has a non-negligible impact on employment, which mainly manifests that environmental governance has a positive impact on employment. Secondly, on the basis of the existing research on the relationship between environmental governance and employment, this paper combines the C-D production function with the mediating effect model. By constructing the path of environmental governance-technological innovation-employment, the paper aims to solve the impact of negative externalities of environmental governance on employment. In addition, taking investment in pollutant governance and the SO<sub>2</sub> removal as the indicators of environmental governance, this paper studies how environmental governance affects employment through technological innovation under these two indicators. Finally, using OLS, FE, 2SLS and GMM related robustness tests to examine the relationship between variables and employment, it is found that environmental governance will have a positive impact on employment in the case of strengthening technological innovation, which again verifies the robustness of our conclusion.

Under the background of the great development of globalization, ecological civilization and the construction of harmonious society, constructing an economy-ecology-people's livelihood employment harmonious development society will be the main problem that China and even the whole world will face in the future, and it is also the comprehensive problem that the government needs to solve urgently. The formulation of policies requires comprehensive consideration of economic, social and people's livelihood effects. Therefore, this paper explored the employment effect of negative externalities in environmental governance, which had important policy

implications on how to achieve the win-win situation of environmental governance and employment. (1) Based on the positive relationship between environmental governance and employment, we can find that there is no conflict between strict environmental governance and employment. Therefore, the Chinese government should appropriately strengthen environmental governance and balance the negative externalities brought about by environmental governance with employment. This is not only the need to accelerate economic development and expand employment, but also the realistic need to achieve the harmonious development of people's livelihood and environment. (2) Considering the high-pressure environmental governance may bring some negative externalities, such as the adverse effects on employment. Therefore, in order to alleviate the impact of negative externalities of environmental governance on employment, the government is encouraged to increase technological innovation and technology investment while carrying out environmental governance to provide technical posts and opportunities for skilled workers to re-employment. (3) In terms of the two measures of environmental governance, namely, investment in pollutant control and the SO<sub>2</sub> removal, the means of environmental governance are different, and the impact on employment is also different. The reason is mainly due to the differences in economic development level, technical level and industrial structure of various provinces, and environmental governance will also have a differential impact on employment. Therefore, the government should give full consideration to the level of economic development, scientific research level and industrial structure of each region, formulate differentiated environmental governance policies, avoid carrying out "one-size-fits-all" environmental governance to mitigate the negative externalities of environmental governance. Thereby achieving a win-win situation of environmental friendship and social employment.

In conclusion, through the path of environmental governance-technology innovation-employment, we can find that China can reduce the negative externalities of environmental governance and achieve a win-win situation of environmental governance and employment development by strengthening technological innovation in the process of environmental governance. In addition, the mediating effect model based on C-D production function proposed in this study can also be widely used in other research fields at home and abroad, such as environmental governance, labor productivity, enterprise production and so on. It is of great significance to solve the problems of negative externality of environmental governance and low production efficiency, thereby realizing the win-win situation of environmental governance, social employment and economic development, and promoting the harmonious and sustainable development of environment and society. Due to the availability of data, it is currently impossible to

study the impact of environmental governance on business employment from the enterprise level, which will become a major challenge that we need to address in our next research.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

## **Assessment of physico-chemical characteristics of groundwater among different farm sizes in Ainabkoi sub-county, Uasin Gishu County, Kenya**

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Access to quality drinking water is of major concern for sustainable development in developing countries with regard to physico-chemical properties. Groundwater from shallow wells is the main source of domestic water supply for the community of Ainabkoi Sub-County of Uasin Gishu County in Kenya. Seasonal agricultural production activities expose the water to possible pollution. In this regard the study aimed to assess the seasonal physico-chemical parameters in shallow wells among different farm sizes in three wards within Ainabkoi sub-county. Each ward was a homogenous stratum of same size-ranged farms classified as large, medium and small farm sizes in Ainabkoi, Olare and Kaptagat (Kipsinende) wards respectively. Within each ward farms were purposively and randomly selected such that only accessible farms that had access to either a privately owned or communal wells were selected. Wells were sampled during the wet and dry seasons of the year for a period of two years. The seasonal levels of physico-chemical parameters pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Total Suspended Solids (TSS), turbidity and temperature were determined. There were non-significant differences between the farm sizes in the groundwater pH, EC, DO, turbidity and temperature. The groundwater pH values were within the WHO standards range of 6.3 to 8.5. EC values were below the recommended limits of potable water of 250  $\mu\text{ccm}^{-1}$ . TDS and TSS differed significantly between farm sizes. Wells within the small mixed farm sizes had significantly high TDS levels ranging from 30-250  $\text{mgL}^{-1}$ . The TDS values ranged from 32.20-203.30  $\text{mgL}^{-1}$  hence the wells can be classified as fresh water wells. TSS values were significantly higher during the wet season by about 90% and highest in wells within the large sized farms. The turbidity levels were higher than the recommended limits by WHO of at least 5.0 NTU in areas with limited resource availability. In conclusion, the groundwater in Ainabkoi sub-county can conservatively be categorised as safe for domestic use with regard to physico-chemical parameters.

**Key words:** Farm sizes, groundwater, season; physico-chemical properties.

### **INTRODUCTION**

Potable or drinking water is defined as having acceptable quality in terms of its physical, chemical, and bacteriological parameters so that it can be safely used for drinking and cooking (Gadgil, 1998). Drinking water

quality is of major concern in developing countries with regard to microbiological, inorganic contaminants and physico-chemical properties which deteriorate water quality (Sorlini et al., 2003). Communities should have

access to safe drinking water as a basic need to health and sustainable development as outlined in the sustainable development goals (SDGs) which focus on ensuring universal and equitable accessibility of safe water for all by 2030 (6<sup>th</sup> SDG) (Osborn et al., 2015). However, the chemical and biological quality of water is often overlooked in comparison with the quantity view point of water for drinking, domestic and agriculture use (Falowo et al., 2017). Groundwater is mainly contaminated and polluted by anthropogenic activities such as modern farming and other domestic and industrial activities. Since groundwater is a major source of water for domestic water supply, its quality should therefore be of major concern especially in agricultural settings. World Health Organisation (WHO, 2011) recommends regular physical assessment of water quality especially after heavy rains to monitor any temporal changes in important physical characteristics such as colour, odour, turbidity, taste, temperature, solids and chemical characteristics such as acidity, alkalinity and hardness.

The study was carried within Ainabkoi Sub-County of Uasin Gishu County in Kenya. Groundwater is the main source of domestic water supply for the community and is exploited through shallow wells (Uasin Gishu Integrated Development Plan (UGCIDP), 2013). Groundwater is considered to be more stable in quality hence requiring no treatment unlike surface waters, is conveniently available and accessible for the family and wells can be developed at comparatively low costs. However, the groundwater resource in Ainabkoi is exposed to possible pollution from agricultural production activities which may make it unfit for consumption. Mixed farming agriculture (food/commercial crops and livestock-dairy) characterised by different farm sizes is the predominant economic activity for the rural community of Ainabkoi Sub-County with farmers gradually shifting to intensive horticultural farming (UGCIDP, 2013). For purposes of this study different farm sizes were determined as a working farm typology because it captured common characteristics within farms in each ward within Ainabkoi Sub-County. According to Ojiem et al. (2006) the heterogeneity of farming size is created by several biophysical and socio-economic factors. However, official farm typologies in Africa are almost nonexistence due to general state withdrawal in agricultural public policies (Matus et al., 2013). The selection of factors that define farm typology varies greatly from study to study and may be governed by the purpose of research (Goswami et al., 2014). Therefore farms in Ainabkoi, Kaptagat and Olare wards were classified as large, medium and small farm sizes respectively. There are also concerns with the notable upsurge of chronic diseases such as cancer reported

within the county in the recent past with a total of 5,137 various cancer cases documented between 2004 and 2012 (Kirumba, 2014).

In view of the foregoing and in line with the county objectives and concomitant strategies aimed at improving access to clean and potable water to the community it became imperative to assess the seasonal quality of ground water. This will provide base data and information which is largely non-existent, on the water quality status to policy makers for future management and planning. The study therefore examined the seasonal levels of physico-chemical parameters of the well water among different farm sizes in Ainabkoi Sub-County, Uasin Gishu County, Kenya.

### Description of the study area

Uasin Gishu County lies between longitudes 34° 50' East and 35° 37' West, and latitudes 0° 03' South and 0° 55' North and with a total area coverage of 3,345.2 km<sup>2</sup> and about 202,000 households (UGCIDP, 2013). Uasin Gishu is a highland plateau with a terrain that varies greatly with altitude, ranging between 1500 m above sea level at Kipkaren in the West to 2100 m at Timboroa in the East. There are six sub-counties namely Turbo, Soy, Ainabkoi, Moiben, Kessess and Kapseret in Uasin Gishu (Figure 1). Uasin Gishu is endowed with good land resources and varied agro-ecological potential and is commonly referred to as the bread basket of the country due to the predominant production of rain-fed maize production.

The county has a long cropping season between March and October and intermediate rains which can be divided into two variable cropping seasons. The first rains normally start at the end of March and the second at the end of June. Average rainfall amounts are sufficiently high and range between 624.9 to 1,560.4 mm with two distinct peaks occurring between March-May and June-September and a dry spell occurring between November and February. The study was conducted in 2012 and 2013 in three wards within Ainabkoi sub-county namely Ainabkoi, Olare and Kaptagat (Kipsinende) which have extensive agricultural activities. A baseline reconnaissance farm survey found that farmers predominantly practiced mixed farming whereby they grew maize, kept some farm animals, and had a variety of vegetables and fruit crops in small gardens beside their homes.

However, each farm had its own unique characteristics with regard to the farm sizes, number and types of domestic animals kept, the maize acreage, variety of vegetable and fruit crops grown, and the homestead/property development such as landscaping, housing,

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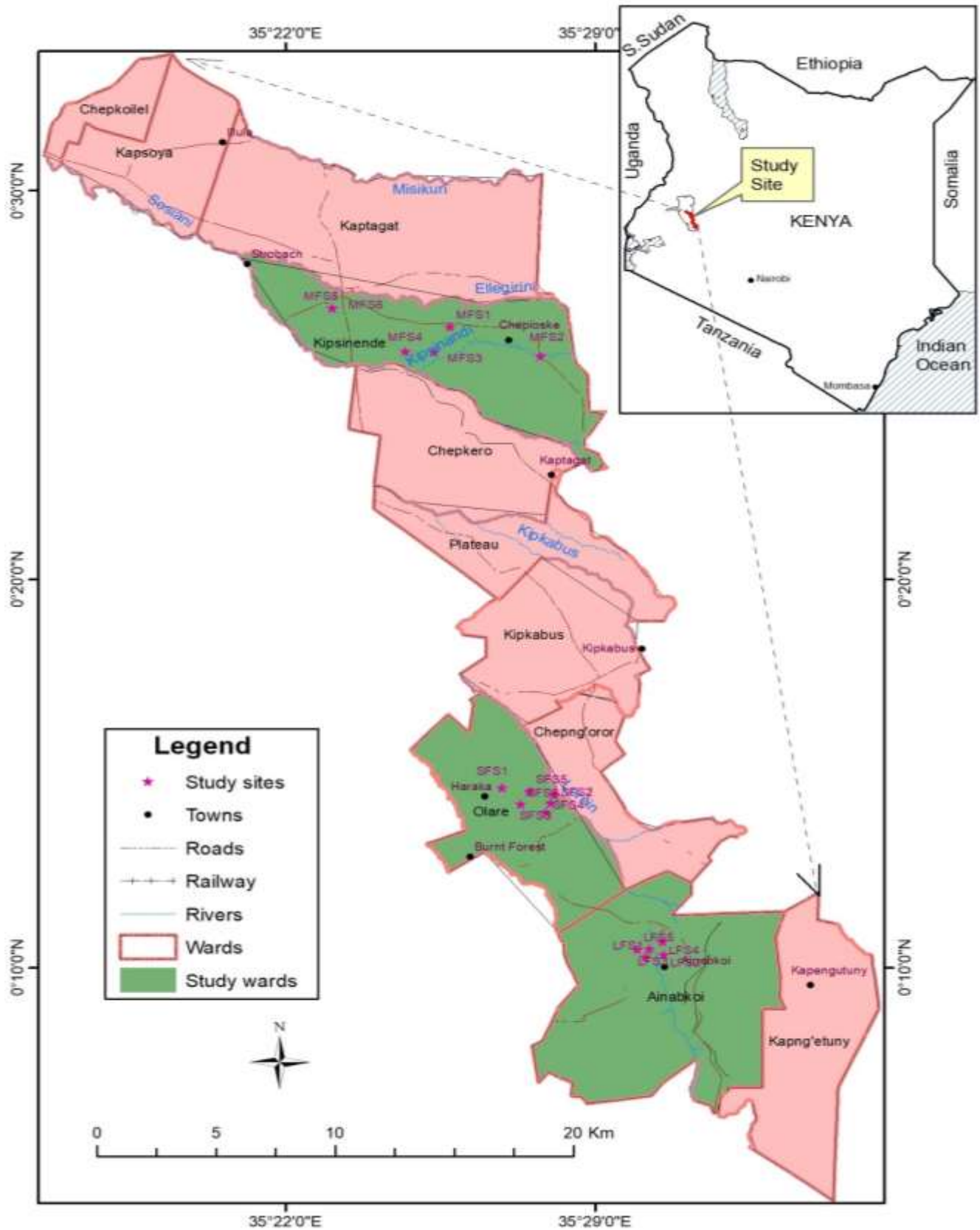


Figure 1. Map of Ainabkoi Sub-County showing the sampling sites. Source: Extracted from Topographic Maps of Kenya (Scale 1:50,000).

toilet construction, well ownership and construction. In order to conceptualize and establish effective comparison between farms it was necessary to conceive a working typology that captured a common characteristic within farms. It was identified that farms in Ainabkoi ward were mainly large, family-generations-owned mixed farming size and ranged more than 40 acres in size (>40 acres) with privately owned wells. In Kaptagat ward, farms were medium sized (10-40 acres) mixed farms with privately owned wells. The farms in Olare ward were small mixed farm sizes which ranged 2-10 acres in size and with communally owned wells. In view of the foregoing, the three wards were identified as non-overlapping strata and farms were stratified on the basis of farm sizes into three farm typologies. Each ward was therefore considered as a stratum of homogenous farms characterised by individual farm sizes with the same extensiveness or size in terms of acreage and accessibility to a well. Purposive random sampling technique was applied in selection of the representative farms within each ward whereby only accessible farms that had access to a well for evaluation of the groundwater sources were selected. Five farms in each ward were therefore identified for well water sampling. Hence a total of 15 wells were sampled during the wet and dry seasons of the year for a period of two years. The well coordinates in Ainabkoi ward were within the latitude range of 0°10'19.4"N to 0°10'33.9"N and longitudes 35°30'03.9"E to 35°30'34.9" E. In Kipsinende ward the well coordinates ranged from 0° 25' 45"N to 0° 26' 59"N and 35° 23' 4"E to 35° 27' 47"E and in Olare from 0° 14' 8"N to 0° 14' 38"N and 35° 26' 55"E to 35° 28' 6"E. The rain or wet season (WS) usually occurs as from March to August while the dry season (DS) is from November to February. It was assumed that the possible variations due to the unpredictable cause-effect impact chain of the agroecosystems and the environment were negligible and that the interaction between farm sizes and year had no agronomic meaning and was therefore less important than the interaction between farm sizes and season. Therefore repetition over seasons was preferred to repetition over years.

## MATERIALS AND METHODS

### Water sample collection

Groundwater samples were collected at least every week from just before planting, in January to March, during planting in April and through to two weeks after topdressing in June-July and thereafter at least once a month until after harvesting in October in 2012 and 2013. Sampling of groundwater was also done at least once a month during off production season in the months of November to January. The purpose of the sampling times were aimed at monitoring any possible temporal changes in groundwater characteristics throughout the production cycle and during off season. Groundwater sampling was done in triplicates at each sampling time, directly into clean high density 150 ml polyethylene bottles, sealed and stored in an icebox in the field and transported to the laboratory within the same day. Samples were transported

immediately to Kenya Marine Fisheries research institute, (KMFRI) laboratories and kept frozen prior to analysis.

It was expected that the nutrient levels in the water samples would not be significantly changed through freezing since it is considered an effective means of nutrient preservation in water samples (Fellman et al., 2008). Unstable hydrochemical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured *in situ* (in the field) immediately after collection of samples while the others were analysed in the laboratory as described by the American Public Health Association (APHA, 1995).

### Determination of pH, EC and TDS

The pH, EC and TDS parameters were measured in-situ using a combined pH/EC/TDS combo (Hanna instruments) Model HI 98130 by selecting the target mode. The probe was submerged into the sampled water and readings taken when they stabilised. Any electromagnetic interference was minimised by using plastic bottles to hold the water samples. TDS was then determined by the method of O'wen (1979), by multiplying the EC value of the water sample by 0.65.

### Dissolved oxygen

Dissolved oxygen was determined by using the Winkler's method according to APHA (1995).

### Total suspended solids (TSS)

The concentration of total suspended solids was estimated gravimetrically on glass-fibre filters (Whatman GFC, or Ederol BM/C filters) after drying to constant weight at 95°C (APHA, 1995).

### Turbidity

Turbidity was measured using a Hatch Turbidimeter 2100 P (APHA, 1995). Turbidity is the cloudiness of water as a result of suspended material such as clay, silt, organic/soluble organic, planktonic, microscopic organism thereby inhibiting light transmission by scattering and absorption rather than being transmitted in a straight line (APHA, 1995).

## RESULTS

The comparison of the mean values for the physico-chemical characteristics of groundwater in the different farm size in 2012 and 2013 are shown in Table 1. There were non-significant differences between the farm size in the water pH, DO, EC, turbidity and temperature. However, there were highly significant differences between the farm sizes in the TDS and the TSS. The small farm size had significantly the highest TDS compared with the large and medium mixed farm size. The TSS levels were significantly highest in the large farms size and least in the small mixed farm size. Turbidity was the only physico-chemical characteristic in the wells that exceeded the permissible levels by World

**Table 1.** Comparison of average of physico-chemical analysis of water samples in different farm sizes in Ainabkoi Sub-County.

Physico-chemical characteristics	Farm size					
	Large	Medium	Small	Isd	Significance P≤0.05	WHO (2008)
pH	7.42 <sup>a</sup>	7.48 <sup>a</sup>	7.44 <sup>a</sup>	0.99	ns	6.5-9.5
Dissolved Oxygen(mgl <sup>-1</sup> )	6.56 <sup>a</sup>	6.69 <sup>a</sup>	6.78 <sup>a</sup>	0.45	ns	N.A
Electrical Conductivity(μScm <sup>-1</sup> )	87.58 <sup>a</sup>	92.44 <sup>a</sup>	88.45 <sup>a</sup>	8.52	ns	250
Total Suspended Solids (mgl <sup>-1</sup> )	76.44 <sup>a</sup>	60.89 <sup>ab</sup>	40.91 <sup>b</sup>	23.87	**	N.A
Total Dissolved Solids (mgl <sup>-1</sup> )	80.31 <sup>ab</sup>	65.44 <sup>b</sup>	106.10 <sup>a</sup>	26.29	***	1000
Turbidity (NTU)	85.98 <sup>a</sup>	85.69 <sup>a</sup>	88.35 <sup>a</sup>	13.06	ns	24.5
Temperature (°C)	24.42 <sup>a</sup>	24.81 <sup>a</sup>	24.48 <sup>a</sup>	0.57	ns	

Means followed by the same superscript within a row are not significantly different at 5% significance level according to Fisher's protected LSD test. <sup>ns</sup>, \*, \*\*, \*\*\*, Non-significant, significant at P≤ 0.05, 0.01, 0.001, respectively.

**Table 2.** Groundwater physico-chemical characteristics during the wet and dry seasons of 2012 and 2013.

Physico-chemical characteristics	Season					
	Wet	sd	Dry	sd	t-test	sed
pH	7.43	0.53	7.87	4.95	-1.12ns	0.40
Dissolved Oxygen (mgl <sup>-1</sup> )	6.75	0.90	6.51	1.13	0.04*	0.12
Electrical Conductivity (μScm <sup>-1</sup> )	88.21	24.13	91.35	35.44	0.92ns	3.43
Total Suspended Solids (mgl <sup>-1</sup> )	74.38	104.85	39.20	56.38	3.69***	9.53
Total Dissolved Solids (mgl <sup>-1</sup> )	90.75	121.01	78.28	58.25	1.16ns	10.75
Turbidity (NTU)	83.56	49.14	89.99	43.32	1.23ns	-5.24

<sup>ns</sup>, \*, \*\*, \*\*\*, Non-significant, significant at P≤ 0.05, 0.01, 0.001, respectively.

Health organisation (WHO, 2011) of at least less than 5 NTU in rural supplies. The average turbidity levels in the sampled well water were 86.67 NTU. The average values of the groundwater physiochemical characteristics were determined and compared for the wet and dry seasons of 2012 and 2013 (Table 2). There were no significant seasonal differences between the wet and dry seasons in the pH, EC, TDS and Turbidity in the groundwater.

## pH

The pH of the groundwater samples in all the farm size ranged from 5.94 to 8.96 in 2012 with an average of 7.41 and 6.6 to 8.96 with a mean of 7.49 in 2013. The pH of the groundwater samples ranged from 5.94 to 8.66 during the wet season with a seasonal average pH of 7.43 and from 6.46 to 8.96 with a mean value of 7.87 in the dry season (Table 2). However, it was observed that the pH fluctuated considerably within each individual well throughout the production cycle. The general trend observed was that most wells had a pH level averaging about 7.5 with a few wells within the medium and small mixed farm size that had pH levels of 8.0 during the wet and dry season.

## Dissolved oxygen (DO)

The DO levels in the groundwater samples ranged from

3.01 to 8.79 mgL<sup>-1</sup>. There were no significant differences in the dissolved oxygen levels between the wells in the different farm sizes (Table 1). However, there were significant differences in the DO levels in the wet and dry seasons (Table 2). The DO ranged from 3.90 to 8.72 mgL<sup>-1</sup> with a mean of 6.75 mgL<sup>-1</sup> during the wet season and from 3.01 to 8.79 mgL<sup>-1</sup> in the dry season with a mean of 6.51 mgL<sup>-1</sup>. These results indicate that the DO levels were higher during the wet season than the dry season by a margin of 3.7%.

## Electrical conductivity (EC)

The EC values in the groundwater samples ranged from 5.32 to 290 μc cm<sup>-1</sup>. The ANOVA showed that there were no significant differences in EC values between the farm size (Table 1) and also no-significant seasonal variations in the EC values (Table 2). The conductivity of the water samples varied from 38.77-146 μScm<sup>-1</sup> with a seasonal average of 88.21 μScm<sup>-1</sup> during the wet season, while it varied from 5.32-290 μScm<sup>-1</sup> during the dry season and a seasonal average of 91.35 μScm<sup>-1</sup>.

## Total suspended solids (TSS)

There were highly significant differences in TSS between the wells in the different farm sizes (Table 1). The TSS



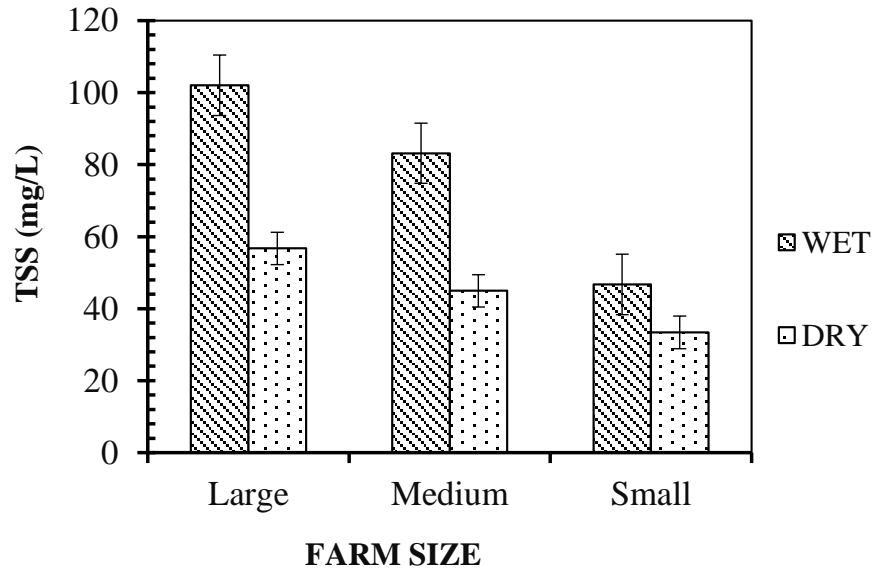


Figure 2. Seasonal variation of TSS in three different farming size.

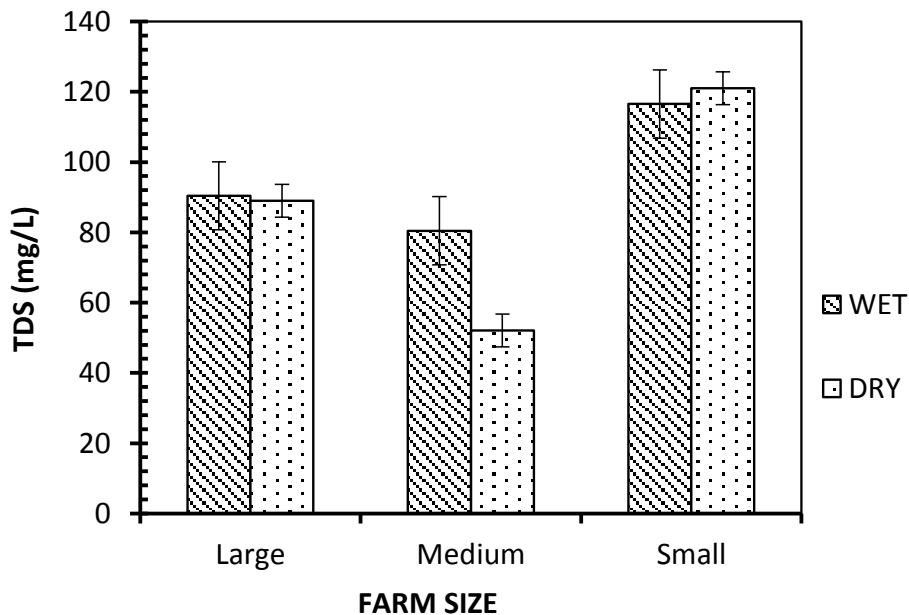


Figure 3. Seasonal variation in the TDS in different farm size.

were highest in wells within the large farm size with values varying from 8.67-247.1 mgL<sup>-1</sup>. The TSS values in well water on average ranged from 12.2-273.5 mg/L in the medium farm size and 9.2-150.3 in the small farm size. The TSS values were significantly higher during the wet season than during the dry season by about 90% (Table 2). The TSS concentration during the wet season was highest in wells within the large farm size, and lowest in wells in the small farm size (Figure 2).

**Total dissolved solids (TDS)**

Analysis of variance showed highly significant differences between well water samples in the different farm sizes (Table 1). Wells within the small mixed farm size had significantly the highest levels of TDS ranging from 30-250 mgL<sup>-1</sup> and averaging 119 mgL<sup>-1</sup> (Figure 3). The content of TDS in well water in the large farm size ranged from 33-168 mgL<sup>-1</sup> with an average of about 90 mgL<sup>-1</sup>,

while in the medium farm size TDS concentration ranged from 10-188 mgL<sup>-1</sup> with an average of 66 mgL<sup>-1</sup>. There were non-significant seasonal differences in TDS levels in well water (Table 2). The seasonal TDS values ranged from 32-202 mgL<sup>-1</sup> during the wet season and 58-136 mgL<sup>-1</sup> during the dry season. The TDS in the well water did not exceed the maximum allowed limit of 1000 mgL<sup>-1</sup>.

### Turbidity

There were no significant differences in turbidity between the farm sizes (Table 1). The turbidity averaged across the farm size varied from the lowest value of 22.5 to the highest record of 119.9 NTU. There were non-significant seasonal differences in the turbidity level of the sampled well water. The average turbidity levels ranged from 22.7-119.9 NTU with a mean of 70 NTU and 20.4-113 NTU with a mean of 76 NTU were during the wet and dry seasons respectively.

### DISCUSSION

The pH values in the sampled groundwater were within the WHO standards of 6.5 to 8.5 (WHO, 2011). The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range 6.5-8.5. Anim-Gyampo et al. (2014) reported closely similar results whereby borehole water pH ranged between 5.77 and 8.3. These results therefore indicate that the well water samples represented satisfactory water pH values for drinking and domestic water use. Seasonal pH variations showed that the average pH values were slightly lower during the wet season (pH 7.4) than during the dry season (pH 7.5). These results concur with those reported by Olutona et al. (2012) who reported lower pH of 7.25 during the wet season and 8.08 during the dry season, an indication of lower levels of hydrogen ions. According to Hounslow's classification of wells, (Hounslow, 1995) as being either moderately acidic (4-6.5), neutral (pH 6.55-7.8) or alkaline (pH 7.8-9), 71% of the wells in 2012 and 54% in 2013, can be classified as being neutral pH (pH 6.5-7.8). According to the classification, on average only 4.5% and 4% of the wells were moderately acidic (pH 4-6.5) during the wet and dry seasons respectively. Although there are no health-based drinking water standards for pH, an optimum pH of 6.5-9.5 is recommended (WHO, 2008). The United States of America Environmental Protection Agency (USEPA) has established a secondary standard for pH range of 6.5-8.5, because pH within this range can produce aesthetic effects such as staining and scaling of equipment and lead to dissolved concentrations of some metals associated with health effects (Fisher et al., 2004).

The level of DO in the wells was relatively higher compared with DO (3.56-5.13 mgL<sup>-1</sup>) in wells in Nigeria (Imoisi et al., 2012). The DO seasonal variations were similar to results of groundwater quality assessment of boreholes in Nigeria whereby wells had slightly higher DO during the wet season than during the dry season (Ornguga, 2014). This can be attributed to the mixing caused by rapid flow of excess rain water. There are no health-based guideline values for dissolved oxygen in water (WHO, 2008). However, since depletion of DO encourages microbial conversion of nitrates into nitrite, which is harmful, it is considered advantageous to have higher levels of DO in the water, (WHO, 2008).

The specific electrical conductivity or EC values in the sampled well water were below the recommended limit of 900  $\mu\text{Scm}^{-1}$  acceptable for drinking water (WHO, 2008). Conductivity does not directly indicate water quality and therefore there are no health or water-use standards based on this parameter. However, conductivity indicates the presence of dissolved solids and contaminants especially electrolytes but does not give clarity about specific chemicals. Conductivity measures the capacity of water to pass an electric current, and will therefore increase with increase in presence of inorganic dissolved solids such as nitrate, sulphate and phosphate anions and ammonium, sodium, magnesium, calcium, iron and aluminium cations (Spellman, 2008). The slightly higher values obtained during the wet season could be ascribed to the surface run-off of leachates into the ground water. Similar results were reported in groundwater in Bunkpurugu-Yunyo, Ghana, with an average EC of 413.46  $\mu\text{Scm}^{-1}$  during the wet season and 356.88  $\mu\text{Scm}^{-1}$  during the dry season (Anim-Gyampo et al., 2014).

TSS are the suspended particulate material in water. There are no internationally set health or cosmetic standards for TSS in water. However, the maximum allowable value by the government of Kenya for domestic water is 30 mgL<sup>-1</sup> Republic of Kenya (ROK, 2005). The TSS values in the study area were often higher than the maximum allowable and were significantly higher during the wet season and in wells within the large farm size. The higher values during the wet season can be attributed to the increased water flow that may carry more suspended solids. Water high in TSS may also contain high amounts of metals that may have health or safety implications because some metals are preferentially sorbed onto the matrix of suspended material (WHO, 2008). Some water quality monitoring groups such as the Kentucky Pollution Discharge elimination size recommends that TSS levels be less than 35 mgL<sup>-1</sup> (Fisher et al., 2004). Suspended solids also provide surfaces on which pathogens often adhere to in water (WHO, 2008) and can therefore increase water contamination.

TDS is a measure of all dissolved substances in water, including organic and suspended particles that can pass through a very small filter and inorganic salts mainly

calcium, magnesium, potassium, sodium, hydro-carbonates, chlorides and sulphates (WHO, 2008). The TDS values obtained in all the wells did not exceed the recommended maximum limit of drinking water by the WHO (2008) of 1000 mgL<sup>-1</sup> for drinking water and also by United States Environmental Protection Agency drinking water standard of 500 mg/L total dissolved solids (Fisher et al., 2004). Similar seasonal variations were recorded from a study on the quality of drinking water in Ghana, where the TDS of the samples ranged from 34.8 to 502 mgL<sup>-1</sup> averaging 248.86 during the wet season and ranging from 23.9 to 355 mgL<sup>-1</sup> with an average of 178.51 mgL<sup>-1</sup> during the dry season (Anim-Gyampo et al., 2014).. Similarly, groundwater assessment in a typical urban settlement in South Nigeria indicated that the water was fit for consumption with TDS values ranging between 74 to 260 mgL<sup>-1</sup> (Imoisi et al., 2012). Freeze and Cherry (1979), classified groundwater on the basis of TDS as fresh water when values range 0-1000 mgL<sup>-1</sup>. In this study all the groundwater samples analysed had TDS values below 1000 mgL<sup>-1</sup> baseline for fresh water, hence, according to the classification of groundwater by Freeze and Cherry (1979), these wells have fresh water. TDS and EC values are general indicators of the suitability of groundwater for various uses. According to Mazor (1991), potable water can have up to 500 mgL<sup>-1</sup> of TDS and be slightly saline water which is adequate for drinking while irrigation can have 500 to 1,000 mgL<sup>-1</sup> TDS. Water that has TDS values greater than 500 mgL<sup>-1</sup> has an unpleasant taste and may stain objects or precipitate scale.

Turbidity is a relative qualitative measurement of the amount of light that is scattered or absorbed by either organic or inorganic matter or a combination of the two (WHO, 2011). Since turbidity measures the light scattering combined effect of the suspended particles in water samples, it is a simple indicator of water quality and serves as a surrogate for other factors or conditions. It is therefore important in determining the quality of water because pathogenic organisms can hide on the tiny colloidal particles and cause gastroenteritis (USEPA, 1999). High turbidity can therefore be an indicator of higher concentrations of bacteria, nutrient, pesticides or metals. The colloidal materials in turbid water provide adsorption site for chemicals that may be harmful to health or cause undesirable taste or odour in drinking water (WHO, 2011). Metals, semi-volatile organic compounds (SVOCs), petroleum hydrocarbons and polychlorinated biphenyls (PCBs) easily adsorb to suspended solids. The turbidity levels in the groundwater samples were largely higher than the recommended values by WHO (2011) of less than 5 NTU. The groundwater appeared to be slightly more turbid during the dry season than during the wet season. Turbidity could have been as a result of contamination of the shallow and unprotected wells from surface runoff during rains, bringing in suspended matter or solids, silt or clay,

organic compounds such as animal dung, plankton and other microscopic organisms or from groundwater flow from other areas. These seasonal differences were also reported in Bunkpurugu-Yunyo, Ghana with turbidity values averaging 8.81 and 13.24 NTU during the wet and dry seasons respectively (Anim-Gyampo et al., 2014). The highest value of 96 NTU was recorded during the dry season and 73 scored during the wet season which were extremely higher than the recommended maximum value by World Health Organization of 5 NTU. High turbidity values of 34 NTU were also reported by (Adekunle et al., 2007), in Abeokuta, Nigeria, while Imoisi et al. (2012), recorded low turbidity values range between 1.05 and 1.35 NTU. According to WHO (2011), a properly constructed well should have water with a turbidity of 5 NTUs or less which is acceptable to many consumers although this may vary with localities. At this level of turbidity, suspended solids cannot be seen by the naked eye, a stable drawdown is attained (avoids turbulence); and microbial activity is minimal.

## Conclusion

The groundwater in Ainabkoi Sub-County can conservatively be categorised as safe for domestic use with regard to physico-chemical parameters. The electrical conductivity and turbidity levels are the basic parameters that should be regularly monitored because of the characteristic relationship between dissolved ions and suspended matter with and EC. There is need to develop health-based guidelines on possible health effects associated with ingestion of water with levels of TDS, TSS, turbidity and EC. However, in order to check overflow into wells, it would be recommended to construct walls around the wells. Further research into building the dataset on the wider water quality status such as bacterial contamination is necessary for sustainability.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# **The role of an environmental engineer in preventing and reducing environmental stress**

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**Environmental engineer is concerned with the protection and prevention of the environment and develops the solution to environmental problem. Environmental engineer ensures work place hazards and environmental health and safety related policies and procedure are communicated to employer and employees, ensures the availability of medical surveillance programme in assisting employer and employees in the course of potentially hazards, that can pose immediate danger to health and safety, encouraging conducive environment for stress free conditions in the environment. Consequently, restriction of stress to condition where an environmental demand exceeds the national regulatory capacity of an organism, in particular situations that include unpredictability and uncontrollability also ensuring employees are properly trained for their jobs and environmental health and safety obligation are carried out by everyone involved.**

**Key words:** Environment, stress, engineer, health and safety.

## **INTRODUCTION**

The role of an environmental engineer in an establishment is preventing and reducing environmental stress (health), hence he lays more emphasis on these components, stress (health), environment, safety and engineer. Stress is defined as non-specific response of the body to any demand for change. It could be a negative, physical, emotional or nervous system response. Stress is also a state of mental or emotional strain, tension resulting from adverse and demanding circumstances; example emotional stress from job or work and family, (Segal, 2017). Stress could be a situation, variable or circumstance that interrupts the normal functioning of an

individual and most of the time carries a threat. It causes both mental and physical ill health. Stress is also a physiological response of an individual to environmental stress that affects their performance and well being.

Environment is defined as the total planetary inheritance and the biotic and abiotic factors that influence each other, (Winpenny, 1996). Environment involves the inter-relationship between these biotic and abiotic components of the environment. It is also all the natural materials and living things.

Moreover, environment is something we are very familiar with and affects our ability to live on the earth, the

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air we breathe, the water that covers most of the earth's surface, the plants and animals around us, and much more (Thissen and Agusdianata, 2008). Environment is everything around living beings, especially the circumstance of life of people and society in their life conditions. It comprises the set of natural, social and cultural values existing in a place and at a particular time, that influence in the life of human beings and in the generation to come (Cambridge English Dictionary).

Environmental stress is the response to things around us that cause stress, such as noise coming from quarry industry or fabrication industry, pressure from work or exhausting work schedules resulting from over-use of employees. Stress that is left unchecked can contribute to many health problems such as high blood pressure, heart disease, obesity, diabetes and depression. Environmental stress is a price shaping adaptation and evolution in a changing environment. It changes the conditions and causes the reduction in performance or fitness. Environmental stress is a significant impact on evolutionary and ecological processes that affects and shapes the genetic, as extensively discussed by Tourigny et al. (2010) in their work, stress episode in aviation, the case of China. It is considered to be primarily a response to physical features of the environment, also a condition of impaired fitness of the environment or an organism (Baba et al., 2009).

### Aim and objectives

The aim of this study is to restrict stress to condition where an environmental demand exceeds the natural regulatory capacity of an organism, in particular situations that include unpredictability and uncontrollability, meanwhile the objectives are to:

- (i) Control stressors that cause environmental conditions that impairs fitness.
- (ii) Cultural environmental factors causing changes in human systems which are potentially injurious.
- (iii) Ensure that environmental, health and safety obligation are carried out by everyone involved.
- (iv) Ensure employees are properly trained for their jobs.
- (v) Reduce environmental allergens caused by exposures to early life, of over crowded households.

### METHODOLOGY

#### Source of stress

There are three main sources of environmental stress. They are physical, chemical and biological sources. Physical stress is an environmental factor or stress that forces the body to compensate for conditions outside the norm. The following are the causes under physical source:

- (i) Time pressure, occurs when there is a limit on a task or

operation. A longer hour on tighter schedules, which causes time pressure and makes human error more likely, that is increases the possibility of human error.

(ii) Work load and overload occurs when the amount of work exceeds maximum working capacity. This causes a lot of environmental stress.

(iii) Fatigue at work occurs when staying at work longer than average period of time. It causes accident, reduces human performance and error.

(iv) Noise can cause physical stress and long term health risks, such as hearing impairment, annoyance and sleep disorders which would decrease performance.

(v) Temperature when higher than ambient level can degrade both mental and physical performances. Thermal stress also caused by cold temperature, affects both health and performance quality.

(vi) Air pollution (both indoor and outdoor).

Indoor air quality is maintained by avoiding smokes, and air infection which can occur through personal contact. Outdoor air pollution is made up of carbon dioxide, sulphur dioxide and others. Carbon dioxide produced by industrial enterprises, vehicles, reacts with hemoglobin in the blood, causing suffocation and allergies. Sulphur dioxide in contact with moist air transforms into sulphuric acid which has a negative impact on the lungs. Also harmful dust can cause havoc when it penetrates the lungs.

(i) Ecological situations are unfavorable in industrial zones, where fairly large deposits are discharged in high populated density area.

(ii) Crowd can cause stress, when establishments over populated with employees cause rowdiness and unhealthy cross breathing.

(iii) Excessive vibration at the work place can cause environmental stress and the human body can be affected.

(iv) Deforestation and destruction of green cover of urban landscape can cause environmental stress.

Chemical sources can cause environmental stress which affects the body. Chemical sources includes the following; flammable gases or liquids stored or disposed at the premises causing stress, which can lead to loss of lives. A good ventilation system must be installed to avoid ignition of flame.

(i) Explosive materials can cause a high level of environmental stress, which may lead to death. They must be securely stored in safe and suitable places, away from people.

(ii) Corrosive substances can destroy or severely damage any material or substance, that is of importance to the establishment and thereby cause an environmental stress.

Biological source of stress. This is an environmental stress that affects the body and makes it tough to perform on day to day basis. It makes employees ill and tired. The following constitute biological sources of stress:

(i) Viruses affect workers. It can spread through the air, via sneezing, cough or by physical contact.

(ii) Bacteria can be ingested, spread by flies and rodents which cause diseases.

(iii) Parasites can be spread through physical contact.

Unsafe environment contributes to chronic stress, non-compliance to safety measures, and unhealthy maintenances are generally associated with distress, prevalence of mental health problems, and with health-impairing behaviors that are also related to stress (NSF, 2013).

In the other hand, an engineer is a professional that is competent by virtue of his/her fundamental education and training to apply the scientific method and outlook to the analysis and solution of engineering problem (Wikipedia, 2017). He takes personal

responsibility for the development and application of engineering science and knowledge, notably in research, design, construction, manufacturing, superintending, and managing in the scientific innovation. Moreover, (Anyata et al., 2001) in their Engineer and society stated that an engineer develops new technological solutions and takes the responsibilities of defining problems, conducting, narrowing research, analyzing solutions, and making decision.

### Importance of the environmental engineer

In the past decades, there have been growing developments which have been unsustainable due to inaccessibility of the environmental impacts, now the issue is being considered through Millennium Development Goals (Nnodu, 2005). Also, the current generation, in the process of satisfying their basic needs and enjoying a better quality of life, in terms of project development without considering environmental impacts assessment, is going to deprive the future generation of quality life, (Muntemba et al., 1999).

Currently, the loss of biodiversity with the depletion of rainforest and negative effect in the environment and climate, results in the extinction of wild life. Therefore, our way of life is placing an increasing stress we put on resources and environmental systems such as water, land and air, cannot go on forever, (Tenney et al., 2000).

In view of the above issues of environmental impacts in the society and the role of an engineer in saving, protecting and reducing all these environmental stresses that are affecting the sustainable development which is very important considering the negative effects, these stresses can be taken care of by an environmental engineer.

Davis and Cornwell (1998), in Introduction to Environmental Engineering gave importance of an environmental engineer being concerned with the application of scientific and engineering principles for protecting of human population from, the effects of adverse environmental factors, protection of environments from potentially deleterious effects of natural and human activities, and improvement of environmental quality. An environmental engineer also applies science and technology that addresses the issues of energy-preservation, production, asset and control of waste from human and animal activities, (Tchobanoglous et al., 1993). Furthermore, he is concerned with finding plausible solution in the field of Public Health, such as water borne diseases, implementation of law which promotes adequate sanitation in urban, rural and recreational areas. Environmental engineer also involves in waste water management, air pollution control, recycling, waste disposal radiation protection, industrial hygiene, animal agriculture, environmental sustainability, public health and environmental engineering laws (Peavy et al., 1985).

Environmental engineer studies the effect of technological advances on the environment, by conducting studies on hazardous waste management to evaluate the significance of such hazards, advice on treatment and containment and develop regulations to prevent mishaps. Most often, he addresses local and worldwide environmental issues such as the effects of acid rain, global warming, ozone depletion, water pollution and air pollution from automobile exhaust and industrial sources. Obviously he is concerned with economy and sustainability of an environment (PNNL, 2015).

WHO (1999) was of the view that environmental engineer provides advice to the public on the adverse impacts of environmental stress on human and ecological health, which are evident from declining quality of air, water and land at locations in the different countries of the world. Environmental engineer equally advises people on the environmental challenges and promoting a healthy economy, as he predicts earth's climate and ecosystem to environmental stress and prevention in human and ecosystem

health. Moreover, human health and ecosystem health are intertwined, each dependent on the other for sustainability and survival. Over the last century, human activities associated with population growth and industrialization have had the greatest negative impact on the health and quality of environment as observed by (NSF, 2013) in funding environmental engineering. Therefore, it is the duty of an environmental engineer to encourage and advise the stakeholders involved, on how to prevent and reduce the stress attached to environmental impact on human health. The ecosystem is always subjected to environmental stressor on a daily basis such as water and air pollution, global warming, degradation and loss of habitat from economic development. As part of the ecosystem, humans are subjected to the same stressors with significant health consequences, which the environmental engineer must be knowledgeable enough to prevent and reduce its effect on the environment.

### Responsibility for prevention and reduction of environmental stress

An environmental engineer is mostly concerned with protecting the environment by developing solution to environmental problems created by company operations or activities. He assesses the impact of projects in the environment and ensures systems and facilities are compliant with environmental regulations, prevent and reduce the incidence of environmental stresses that can lead to sickness and death (WHO, 1999).

Consequently, every environmental engineer must:

- (i) Ensure that environment, health and safety obligations are carried out by everyone working under his operation;
- (ii) Ensure work place hazards and environmental health, and safety related policies and procedure are communicated to employees and visitors;
- (iii) Ensure that self assessment inspection of environment, health and safety are performed regularly, that records are retained and that deficiencies identified in any inspection are addressed;
- (iv) Ensure individuals working in their operation have the proper safety equipment and personal protective equipment to perform their work safely;
- (v) Encourage prompt reporting of health and safety concerned without fear of reprisal;
- (vi) Curtail work being carried out under his authority if he reasonably believes that continuation of the work poses an immediate danger to health or safety;
- (vii) Inform employees of the availability of medical surveillance programme to assist them in the course of potentially hazards exposures or injuries.

## RESULTS

Analysis shows the stress is characterized as a force shaping adaptation and evolution in changing environments and, and a property of both the stressor and stressed observation gives the evidence of environmental stress as a significant impact on evolutionary and ecological processes that affect and shape the genetic structure and evolution of population Ezeigwe (2015). Moreover, stress is an attribute of both stressor (environment) and stressed (biology). It also experience by organisms or population and couldbecome consequence of changes of either the stressor or

the stressed considering evolutionary perspective of environmental pressure and biological response as integrative, (Johnstone et al., 2012).

Evidence shows that stress has many difference ways, conspiring physiological context, physiological responses of individuals to environmental stresses that affect their performance and wellbeing Tchobanoglous (2003). Avoiding of environmental stressors in the work place which can create an unpleasant atmosphere, poor work performance, absenteeism and possibly even physical injuries must be paramount in any industry finally the emphases land on stress by reduction in fitness of organism or population caused by the environmental factor must be overcome to avoid detrimental impacts, by responding phenotypically or genetically and evolve adaptive mechanisms, Aubin-Horth et al. (2012).

## Conclusion

In conclusion, (AEO, 2013) noted that the existence of stress caused by unhealthy and unsafely environment can induce a rise in certain hormones secreted by the adrenal gland which triggers and increase the heart rate and blood pressure on the employees of the establishment. PNNL (2015) is of the opinion that unconducive and unsafe environment are the factors that mostly cause environmental stress, which can cause ill-health to the employees. Therefore, unhealthy employees are always unproductive and thus a socio-economic problem that could lead to moribund of any establishment (company)

Consequently, an environmental engineer is more qualified to curb the problems of stress. Moreover, his responsibilities as an environmentalist are complying, implementing, communicating and ensuring, adherence to environmental, health and safety, regulations, principles and practice which will be beneficial to the employer, employees and entire establishment (Renald, 2010).

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# **Water quality assessment of various sources in Peri-urban areas of Malawi: A case of Bangwe township in Blantyre**

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**Water supports life at microscopic and macroscopic levels. Good quality water is essential to economic and social growth of a community and a nation at large. Bangwe township in Blantyre is one of the closest townships to the city and provides a reliable workforce and supply of consumables to the city. Due to its overcrowding, there are a lot of issues to do with illnesses that arise from contamination of portable water. They have water resource points that they share communally, apart from others that have their own individual source points. This work aimed at assessing the quality of the most communally shared water points in Lilaka, Mvula, Chikunda, Namiyango and Ntopwa 2 areas of the township. Three major water source points (tap water kiosks, boreholes and water wells) from each community were selected for the study and samples from these sources were analyzed for conductivity, pH levels, total dissolved solids, total suspended solids, turbidity, fecal coliforms, lead and iron. The results showed that the water from these communal water source points are highly contaminated with a *F. coliform* maximum record of  $350.00 \pm 0.03$  cfu/100 ml in Chikunda area and of not pleasant organoleptic characteristics which risk the health of the consumers. This work recommends that authorities should plan to intensify monitoring of water from these sources, inspections and preventive maintenance of boreholes and tap water plumbing systems to check the quality and safety of the water and replace any damaged systems or parts thereof.**

**Key words:** Water quality, water safety, contamination, water points, portable water.

## **INTRODUCTION**

Bangwe township is one of the most important areas to the city of Blantyre. Due to its proximity to the city, it offers a reliable labor force and consumable resources for the city. Compromising the health of the township is

likely to have a huge economic and at worst, a health impact on city dwellers and workers. Clean and good quality portable water ensures a healthy citizenry that can contribute to community and/or national development,

without which, life falters and conflicts for good quality water arise. There is currently limited literature on the quality and safety of water being used in Bangwe and many other such Malawian townships.

Water is a fundamental basis of life both in the animal and the plant kingdoms. It is a valuable and finite resource that is central to the human well-being and socio-economic development. Poor quality water majorly threatens the health of millions of people worldwide (Adekunle et al., 2007). Poor quality of water retards development of people and states through health-related costs which reduce active participation of individuals in developmental activities. Research shows that about 80% of diseases are connected in some way to poor quality contaminated water (Adebayo et al., 2011; Sadallah and Al-Najar, 2015). This contamination is usually a public health concern when it comes from artificial pollution. Pollution of water sources in rural and urban areas remains a serious challenge worldwide especially in many developing countries like Malawi (Mwendera, 2006).

The major artificial pollutants include chemical composition of parent rocks from construction activities, the discharge of chemicals and hazardous materials from residential and industrial sites, agricultural activities and discharge of wastes into water sources from business places and individuals from residences as well as in transit. The sources that are most vulnerable are rivers, boreholes and piped water sources. A number of interventions have been put in place by various organizations and the government to improve the quality and safety of drinking water from these sources in order to meet the sustainable development goal 6 targets number 1 and 3 and Malawi vision 2020. Some of the interventions that have been made are construction of new boreholes, water kiosks, wastewater removal in rivers by city councils, formulation of water legislation and civic education of people in water management in rural and peri-urban areas. After the interventions, there is lack of attention amongst scientists to assess water quality levels of these sources that are now being used by households in the rural and peri-urban areas in Malawi.

### Water quality and safety parameters

Naturally, water contains colloidal matter, minerals, gases, non-electrolytes and electrolytes, contributing to the overall pH of the water which helps to determine water power or ability to cause corrosion (WHO, 2007). Iron is one of the most important natural trace elements human bodies need to survive. Besides being a protein functional component, it activates and stabilizes enzymes

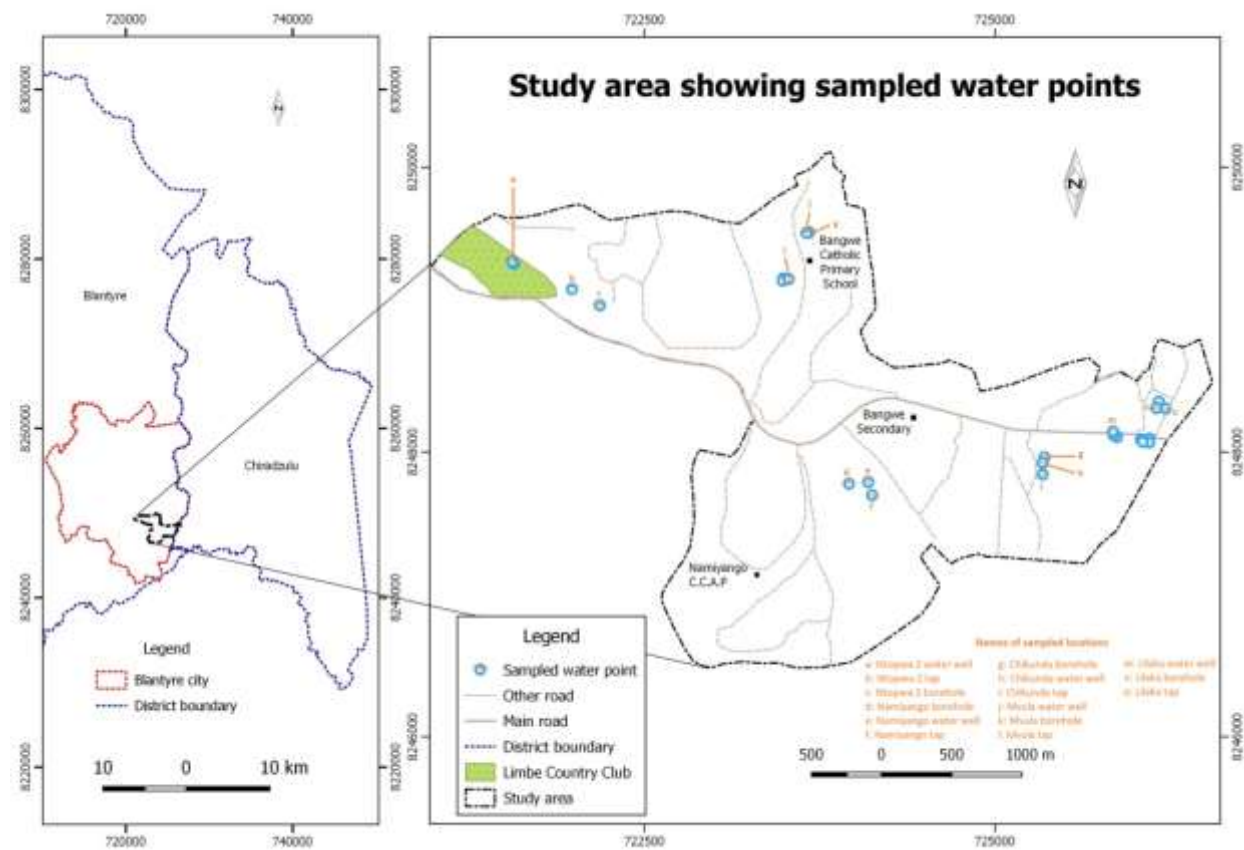
when at low concentrations (Tautkus et al., 2003). Above trace amounts of iron can lead to serious health problems including rapid, shallow respiration, depression, coma, cardiac arrest and convulsions (Alemdaroğlu et al., 2000; Bağ et al., 1998; Paleologos, Giokas et al., 2000). On the other hand, lead (Pb) is a seriously toxic heavy metal to many body organs even at low concentrations, reported to cause deficiency of mental ability in children (Talebi and Safigholi, 2007). High levels or prolonged low levels of Pb can also lead to slow fetal growth, premature birth, cardiovascular and reproductive problems, low IQ and anemia among others (EPA, 2017). A growing public health concern on the presence of lead in drinking and natural water made the Public Health Association reduce the maximum limit of the presence of lead in portable water, from which the European Community recommended 50 µg/L (Talebi and Safigholi, 2007). Metals are generally found in water pipe materials, paints and plastics pigments, acid battery, water treatment coagulants, solder and food colorings among other materials which easily contaminate water sources by discharge (Schock, 1989; Tautkus et al., 2003; WHO, 2009). Metal elements (Fe, Pb and others) are determined spectrometrically and gravimetrically. Gravimetry is considered cumbersome and less precise by some while spectrometry is fast with better precision and accuracy.

Total dissolved solids (TDS) and electric conductivity (EC) are essential parameters in the determination of the amounts of solids in a sample of water. Water EC indicates the amount of ionic solutes from impurities and other contaminants which enable the water to conduct an electric current (Tchnobanoglous and Kreiti, 2002).

Fecal coliforms in water indicate a possibility of serious contamination by pathogens. They can come from latrines and livestock dung (Kaonga et al., 2013). Fecal coliform in water microbiology (organisms that grow at 44 or 44.5°C) produces gas and acid from the fermentation of lactose. Although there are some organisms with same characteristics but being not of fecal origin (generally referred to as thermo-tolerant coliforms), it is almost always that thermo-tolerant coliforms indicate fecal contamination in water, more than 95% of which are *Escherichia coli* (UNEP/WHO, 1996). Fecal coliforms are used in studies as they indicate portable water quality to the effect that they influenced the development of the public health concept (Nikaeen et al., 2009).

Water vendors from Bangwe township sell water collected from different points in Bangwe to travelers and workers in various selling points, including bus terminals and schools. With limited literature on the quality and safety of water from Bangwe township, people from the area and far beyond could be at a risk of diseases from unsafe water. The aim of this study was to conduct a

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**Figure 1.** Location of Bangwe township relative to the economic city of Blantyre and to the right, details of sample collection points.

water quality and safety assessment of various water sources basically used by households in Bangwe, a peri-urban township of Blantyre, Malawi. The study will complement efforts of making sure that the country achieve sustainable development goals 6 and 3 which state that there should be equitable access to safe water and sanitation for all, and healthy lives and the well-being of all people of all ages by 2030 respectively. Therefore, the study will help to inform relevant authorities in advance about water quality of various areas and act accordingly. The undertaking of this research is justifiable because Bangwe township is a vitally important township to Malawi's economic city of Blantyre.

## MATERIALS AND METHODS

### Sample collection

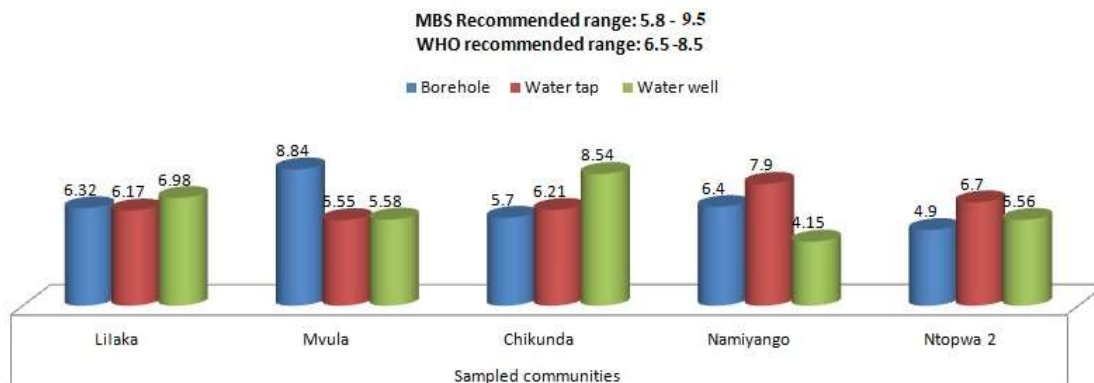
Samples were collected in Bangwe township from five large communities; Lilaka, Mvula, Chikunda, Namiyango and Ntopwa 2 areas. This research focused only on the most reliable sources of portable water that were being used communally in the area

as directed by community leaders. In each community, water was sampled in triplicates from common boreholes, water wells and water tap kiosks. Figure 1 is a map showing the location of Bangwe township in Blantyre city and a detailed locations of the sampling points within the township.

Sample collection was done in two consecutive days (2<sup>nd</sup> and 3<sup>rd</sup> of August, 2018) and samples were collected as described in literature (Uwidia and Ukulu, 2013). Immediately after drawing samples, TDS, pH and temperatures were determined electro-chemically using hand-held meters and samples were kept in a cooler box for further laboratory analyses to avoid biodegradation. All laboratory analyses were started on the same day of sample collection. At the laboratory, analyses started the same day of sampling. Physical and biological characteristics of the samples were determined. The analyses were performed to assess water contamination and quality for drinking.

### Sample analysis

Standard methods from the American Public Health Association (APHA, 2005) were used to determine total dissolved solids (TDS), pH, electrical conductivity (EC), total soluble solids (TSS), turbidity, metal concentrations and fecal coliforms. Briefly, EC and TDS were determined using a hand-held EC/TDS meter. A refractometer (Atago) was used to determine TSS. A calibrated electrode pH



**Figure 2.** pH values of various water samples in the research communities.

meter was used to determine pH and a portable turbidity meter was used to determine turbidity. Iron and lead concentrations were determined using weight digestion where hydrochloric acid and nitric acid were used to free metals from water. An atomic absorption spectroscopy (AAS) was then used to determine the amounts of metals in the samples using flame atomic excitations (APHA, 2005; Twyman, 2005). For fecal coliform determination, a membrane filter (0.45  $\mu\text{m}$ ) was used to pass a water sample in order to retain coliform bacteria on the membrane. A broth (membrane lauryl sulphate) was used as nutrient and the bacteria were incubated in a petri dish at 37°C for 24 h. A microscope was then used to enumerate all yellow colonies and expressed the counts in colony forming units (cfu/ml) (APHA, 2005).

## RESULTS AND DISCUSSION

All the results presented in this paper are the means of triplicate sample tests.

### Water pH levels

The pH of tap water was within the Malawi Bureau of Standards recommended range of 5.8 to 9.5 for drinking water (MBS, 2005) except for Mvula area which could be due to acidic discharge from dissolved metals from plumbosolvency. The pH of borehole water had a maximum of 8.84 and minimum of 4.9 in Mvula and Ntopwa 2 areas respectively and maximum pH values for well water was 8.54 with a minimum of 4.15 in Chikunda and Namiyango areas respectively. The maximum and minimum values are observed to be way out of the recommended safe range of the Malawi Bureau of Standards which already is relaxed from the WHO recommendations. Figure 2 shows a summary of the results for pH in all the sample collection areas.

The pH variations for well and borehole water could be due to solvation of organic matter in the soil matrix surrounding and in contact with the water wells (Mtewa, 2017). These pH levels create a conducive environment for the proliferation of fecal coliforms that survive well

between pH of 5.8 and 8.4 (Kaonga et al., 2013; Lambert, 1974). It is difficult to control well and borehole water pH apart from checking the site before boring and buffering water using recommended acid-base buffers. The lower the pH levels of water get, the higher the potential corrosion levels of the water become (WHO, 2007).

### Iron, turbidity and total suspended solids

The results for Iron, turbidity and total suspended solids are presented in Figure 3.

Amongst the four communities, only Mvula area showed better results (0.31 ppm), slightly higher than the maximum WHO allowable limit of 0.3 ppm. Lilaka (0.6 ppm), Chikunda (0.46 ppm), Namiyango (0.49 ppm) and Ntopwa 2 (0.71 ppm) put the users at the risk of iron toxicological complications. The presence of the metals in the water could largely be due to contamination from pre-contaminated water drawing materials, sawdust particles, organic materials decay with ligands in their structural formations, plumbosolvency for borehole due to low pH water levels and salvation from soil in contact with the water which comes up due to ionic completion in the water as a solution. Tap water and borehole plumbing systems could be too old and liable to corrosion with time, contaminating the water in turn. There was no mention of recent checks of water plumbing system in recent years which shows negligence of engineering inspections and preventive maintenance in the area which are required for the sustenance of quality assurance systems as recommended by Mtewa and Mtewa (2017).

Turbid water is unpleasant for consumers. High levels of turbidity were found in water wells which make scientific sense due to many materials that easily get into the water bodies. This can however be checked in the dry season better than in the rainy season by taking turns when drawing the water at given intervals to avoid agitation of the water.

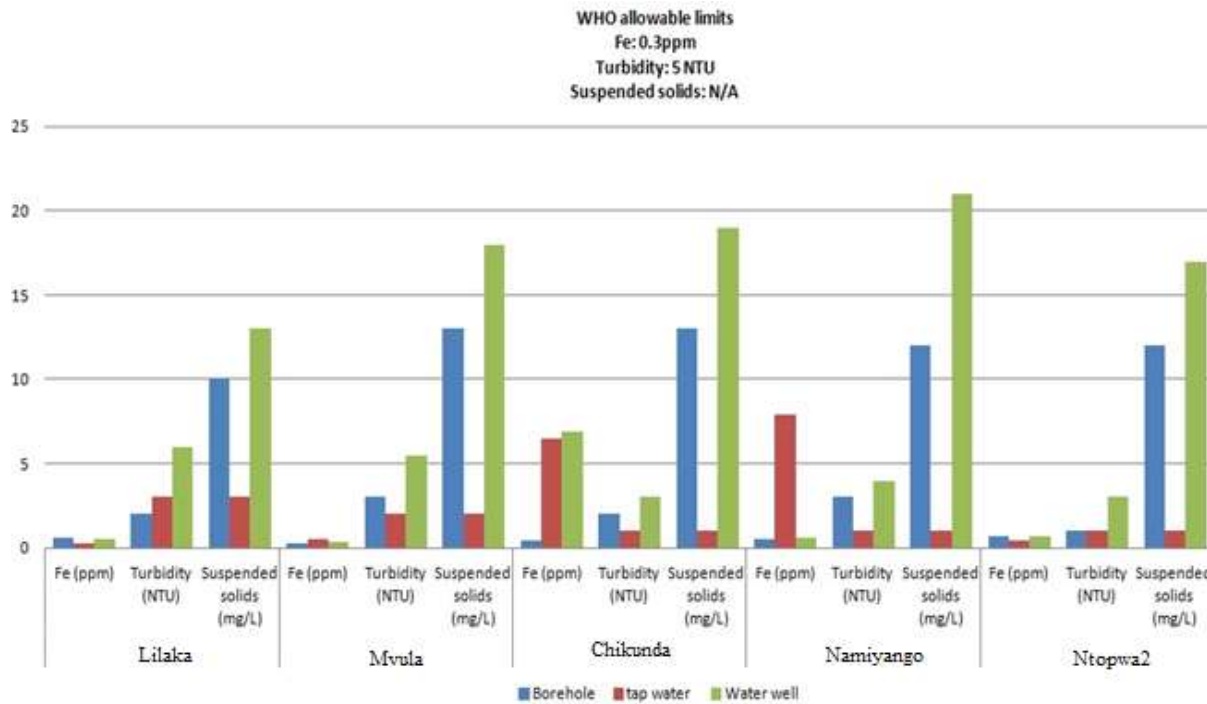


Figure 3. Comparative results for iron, turbidity and total suspended solids in the sampled communities.

Table 1. Results for lead (Pb) in water samples from all the research sites.

Sample name	Lead concentration (mg/L) for water source points		
	Tap water	Borehole water	Well water
Mvula	0.16±0.0014	0.09±0.0013	0.1±0.0004
Chikunda	0.1±0.0003	0.06±0.0003	0.1±0.0003
Namiyango	0.1±0.0001	0.08±0.0002	0.11±0.0002
Ntopwa2	0.07±0.0002	0.08±0.0004	0.11±0.0005
Lilaka	0.09±0.0002	0.1±0.0002	0.1±0.0003

The results are expressed as mean ± standard deviation, n=3.

### Lead content in water samples

The presence of lead (Pb) in all water samples raises a serious concern to the safety of the water that people in Bangwe township are subjected to. With a maximum of 0.16 mg/L lead in Mvula area, frequent exposure to consumers may ultimately lead to lead toxicity in future. These results and those for pH indicate that the plumbing system in Mvula area could be worn out or have several points of possible contamination. It is prudent for authorities to develop a preventive maintenance program that needs to always be adhered to without fail as this is a matter of the life of real people which translates to the intended socio-economic development of the city of Blantyre. Table 1 presents results for lead content in water samples collected from all the five research sites.

Lead concentrations as for any other heavy metal in portable water, needs to be checked and managed to save consumers from detrimental effects of heavy metal toxicity.

### Total dissolved solid and electrical conductivity

Table 2 shows the results of electrical conductivity and total dissolved solids in the water samples from the sampled communities.

The results in Table 2 show that there was high amount of matter in well and boreholes, with more resounding presence in the wells. This could be due to the contamination from dust particles and other materials that find their way into the wells at the time of use or

**Table 2.** Total dissolved solids and electrical conductivity of water samples.

Water source	Lilaka		Mvula		Namiyango		Ntopwa 2		Chikunda	
	TDS (mg/L)	EC ( $\mu$ S/cm)	TDS (mg/L)	EC ( $\mu$ S/cm)	TDS (mg/L)	EC ( $\mu$ S/cm)	TDS (mg/L)	EC ( $\mu$ S/cm)	TDS (mg/L)	EC ( $\mu$ S/cm)
Borehole	188 $\pm$ 1.25	282 $\pm$ 0.00	694 $\pm$ 7.25	1044 $\pm$ 6.00	400 $\pm$ 0.00	601 $\pm$ 0.00	139 $\pm$ 2.25	207 $\pm$ 0.00	159 $\pm$ 0.00	241 $\pm$ 0.25
Water tap	94 $\pm$ 0.00	143 $\pm$ 2.25	129 $\pm$ 0.00	190 $\pm$ 0.00	146 $\pm$ 2.25	218 $\pm$ 5.45	130 $\pm$ 2.25	199 $\pm$ 0.00	127 $\pm$ 0.00	191 $\pm$ 5.00
Water well	180 $\pm$ 1.25	198 $\pm$ 3.77	834 $\pm$ 1.00	1249 $\pm$ 8.25	376 $\pm$ 0.00	558 $\pm$ 6.77	428 $\pm$ 0.00	642 $\pm$ 0.00	338 $\pm$ 0.00	627 $\pm$ 2.13

The results are expressed as mean  $\pm$  standard deviation, n=3.

**Table 3.** Results for fecal coliforms for the research sites.

Site	Fecal coliform (cfu/100ml) for water source points		
	Tap water	Borehole water	Well water
Mvula	0.00 $\pm$ 0.00	9.00 $\pm$ 0.00	12.00 $\pm$ 0.00
Chikunda	0.00 $\pm$ 0.00	0.10 $\pm$ 0.01	350.00 $\pm$ 0.03
Namiyango	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00
Ntopwa2	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	28.00 $\pm$ 0.02
Lilaka	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00

The results are expressed as mean  $\pm$  standard deviation, n=3.

when the wells are left open for some time; waiting for next user. EC values were generally higher than the upper limit recommended by the Malawi Bureau of Standards (150  $\mu$ S/cm) (MBS, 2005) leading to a slightly salty taste of the water (Kaonga et al., 2013). As reported in literature (Uwidia and Ukulu, 2013), high EC values indicate that the water sources had a lot of inorganic ions which had influence on the conduction of electric currents such as Na<sup>+</sup>, K<sup>+</sup>, H<sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>-</sup>, HCO<sup>3-</sup> and others. Fe<sup>2+</sup> and Pb<sup>2+</sup> have been confirmed to be present in this study. High TDS values show that the water sources had high amounts of dissolved solid substances as solid matter, which usually include proteins, carbohydrates, esters and salts (Uwidia and Ukulu, 2013). This is risky as some of the materials into the water bodies could be highly

poisonous or infected, making the wells a health hazard to the community. This is the case with fecal coliform contamination which was higher (350 cfu/ml) than the WHO recommended safe maximum levels of 100 cfu/100mls. It should be noted that fecal contamination was mentioned to be one of the causes of diarrhea pathogens in less developed countries in previous studies (Kaonga et al., 2013). The risk of disease is even higher as the areas of Ntopwa 2, Lilaka and Mvula are highly populated. Overcrowding in the areas contributes to poor hygienic and sanitation practices (Osei and Duker, 2008). The findings show relatively better results on fecal coliforms than those that were reported by kaonga et al., (2013) in Ntopwa area and others. This is an indication of improved hygienic practices facilitated

probably by the dry weather as opposed to the rainy weather the previous study was carried out under.

### Fecal coliforms

The results for fecal coliforms are presented in Table 3. 60% of the sampled well water and 40% of the sampled borehole water are microbiologically not safe for drinking. Despite the levels of care that the people in all sites visited expressed to be adhering to, like covering the wells every time after use, Mvula area, Ntopwa 2 and Chikunda wells still register high levels of poor water sanitation with Chikunda registering as high as 350.00 $\pm$ 0.03 cfu/100 ml of *F. coliforms*

against a WHO maximum limit of absence for drinking water, totally unacceptable for drinking.

Note needs to be taken that consumers in these areas were confident about the sanitation of their water and they were still using the water for drinking and cooking during sample collection. The lack of knowledge of the people of the areas about the quality and safety of their water could be a general scenario with other areas where research of this kind has not yet been undertaken. Dissemination of such findings as these ones and enhanced surgical civic education on basic hygienic practices can help positively change the lifestyles of people in the areas to become more water quality and safety-conscious.

### Conclusion and recommendations

Issues of water quality and safety are critical to health and national development. Citizens could be suffering from cancers and other unknown and untraceable diseases which could be linked to consuming contaminated water some time back. Water from wells are generally found to be not safe and of poor quality probably due to their open nature to the environment, relative to tap and borehole water. High levels of matter and metals in tap water for Mvula area suggest compromised plumbing systems, affecting the portability of the water thereof.

This work revealed no major differences between findings in the rainy season from those in the dry seasons. Perhaps the time it has taken to study some sources of water in the area have seen some practices previously recommended, being compromised with time. Generally, water sources close to market areas and well within overcrowded residential areas of Bangwe have less than pleasant water qualities to ensure safety for the consumer. There is a high risk of contamination with heavy metals and other inorganic and organic substances that could easily lead to human health complications with high or extended exposure. This risk is not only on the people from Bangwe township but also lies on unsuspecting travelers who buy plastic bag packaged water and cooked foods using water from the area.

There is still need to encourage safekeeping of water sources in Bangwe township by communities, starting from simple activities like covering the top openings of wells to regular sanitation talks and decontamination campaigns. There is also need for authorities to check the conditions of the borehole and tap plumbing systems which could likely be too old and easily get corroded, contaminating the water by consumers. There is need for institutions to be carrying out such monitoring projects to ensure right measures and interventions are carried out where necessary.

The results from this work are critical in addressing public health and environmental concerns for Bangwe

area, from which lessons can be drawn to work in other areas too. New knowledge about the quality and safety of water in Bangwe area in the dry season of the year has been added to the scientific database. These results will also be used as a baseline reference point for other subsequent studies to be conducted in the country and beyond. The results will effect meaningful interventions and life style changes on the part of various stakeholders in the water sector in Malawi and beyond.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# **Stakeholders' perceptions on key drivers for and barriers to household e-waste management in Accra, Ghana**

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**Safe management of e-waste has become a major problem for many countries particularly developing countries. This is because e-waste management in an environmentally sound manner (ESM) is affected by many factors in most African countries. To address this emerging urban waste problem, city authorities are devising management strategies that would be acceptable to key stakeholders. This paper evaluates perceived drivers for and barriers to the adoption of e-waste management option in Accra, Ghana from the perspective of households, e-waste workers and institutions. The paper identified four critical factors that could facilitate the adoption of e-waste management option. These include regulatory framework, public health outcomes, education and awareness on e-waste management and good policies and stricter legislation. In addition, the paper identified poor policy framework, lack of or inadequate legal/regulatory framework, low public education and awareness of e-waste management and unhealthy conditions of informal recycling as the four most critical barriers to overcome in the search of e-waste management option. We draw attention of policy makers and waste planners to critically take into consideration the identified drivers and barriers in the adoption of any management option to ensure sound environmental practices.**

**Key words:** E-waste, stakeholders, drivers, barriers, management option.

## **INTRODUCTION**

E-waste being part of urban waste has become an emerging challenge to city authorities and planners due to the magnitude of volume and quantity generated. The increasing volume generated annually in cities worldwide is attributed to rapid urbanization (Babu et al., 2007), rapid changes in technology (Oteng-Ababio and

Amankwaa, 2014) which has resulted in the manufacturing of new designs (Kiddee et al., 2013; Rode, 2012; Tiwari and Dhawan, 2014) and changing lifestyle. Consequently, the management has become an albatross for many countries not only as a result of the volume and rate of waste generation but also because it

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contains several toxic substances which could lead to adverse health and environmental effects (Robinson, 2009; Peralta and Fontanos, 2006) if not properly handled or disposed of (ILO, 2012).

On the other hand, e-waste also tends to contain substantial quantities of valuable minerals such as gold, silver, copper, platinum and other precious metals (Widmer et al., 2005) which could be lost to the waste stream if it is not recovered early. From the aforementioned discussions, it is imperative that while e-waste is a growing environmental and health concern, it also offers opportunities for many people to earn a living (Herat and Agamuthu, 2012).

Studies have shown that e-waste management in an environmentally sound manner (ESM) has been constrained by many factors in developing countries. These include lack of institutional framework, inadequate or absence of effective legislation (Kiddee et al., 2013; Herat and Agamuthu, 2012), and other regulatory controls. Other factors include lack of proper recycling infrastructure (Oteng-Ababio and Amankwaa, 2014; Namias, 2013; Herat and Agamuthu, 2012) and inadequate knowledge on proper disposal practices by households (Kalana, 2010). These have resulted in the adoption of crude and wasteful recycling methods by informal recyclers in developing countries (Oteng-Ababio and Amankwaa, 2014; Nnorom and Osibanjo, 2008).

In response to the increasing e-waste problem, many countries in Europe, North America and Asia have adopted management strategies that incorporate best practices to manage it in an ESM. However, many developing countries are yet to adopt any management strategy to specifically address the e-waste issue. Although extensive research has been carried out on e-waste management in Ghana, no single study exist which adequately covers appraisal of how key drivers and barriers could affect the adoption of e-waste management option.

The objective of this study is to evaluate perceived drivers for and barriers to the adoption of e-waste management option in Accra, Ghana from the perspective of key stakeholders. This study, therefore, while bridging the knowledge gap in the literature, contribute to scholarly debate in the search of e-waste management option in Accra using data of households from three selected communities, e-waste workers and institutions.

## LITERATURE REVIEW

Identifying and adopting appropriate policy and management strategies for waste management, especially e-waste, is a challenging task that requires technical expertise. However, policy formulation and management strategy design is not just a technical

exercise and it is imperative that policy and management strategies should also reflect the values of the community they serve. An important dimension that is significant to policy formulation is drivers and barriers. Drivers are factors which have a positive influence while barriers are factors which have a negative influence. Integrating key drivers and barriers in a synergetic and reinforcing strategy in policy formulation will serve as a framework for appropriate activities towards sound e-waste management.

### Drivers

A review of the literature identified a range of drivers for the adoption of new concepts or policy implementation. Phillips et al. (2002) have identified the main drivers of municipal solid waste management best practice in United Kingdom. According to them, they include policies and legislation, efficient waste institutions, socio-economic factors, education and public awareness as well as various regulatory frameworks established over time.

Similarly, UNEP (2007), Savage et al. (2006) and Babu et al. (2007) observed that public awareness and knowledge of environmental and health impact of e-waste is critical for their management. Additionally, studies by Wilson (2007), Peralta and Fantanos (2006), Zaman (2014), Kiddee et al. (2013), Khetriwal et al. (2007) and Nnorom and Osibanjo (2009) showed that the driving factor for e-waste management best practices in most countries is the formulation of policies and institution of good legislation. Other drivers identified in the literature include community perception, efficient waste management institutions, socio-economic factors, potential market for recycled products, adequate infrastructure for collection, treatment and disposal as well as existence of informal recycling sector (ILO, 2012; Wilson, 2007; Oteng-Ababio, 2012c; Amankwaa, 2014; Oteng Ababio et al., 2014; Chi et al., 2011).

### Barriers

There are a number of key factors which normally put a barrier against sound waste management practices. For instance, ILO (2012) identified absence of data on quantity of e-waste generated and disposed of yearly as a hindrance to effective e-waste management. In addition, ILO (2012), UNEP (2007), Kiddee et al. (2013), Herat and Agamuthu (2012) and Kissling et al. (2013) have identified poor policy framework, lack of or inadequate legislation and regulatory framework as barriers to e-waste management. Other barriers found in the literature include low public education and awareness

on e-waste management (Davis and Herat 2008; Hicks et al., 2005), unhealthy conditions of informal recycling (ILO, 2012; Joseph, 2007; Hicks et al., 2005), unstable macroeconomic environment, lack of involvement of stakeholders in decision making, lack of or inadequate funding, weak waste institutions, high cost and inadequate management infrastructure, and limited capacity of state institutions to deal with waste as well as lack of or inadequate funding (ILO, 2012).

## METHODOLOGY

### Sample population

The population frame for the study consists of electronic assembler/importer, recyclers/dismantlers (waste scavenging), scavengers, refurbishers (classified as e-waste workers for this study), consumers (households), policy makers and implementers (government officials), city authorities, final disposers and environmental non-governmental organizations (NGO) within the study area.

Three communities namely: Agbobloshie, James Town and Korle Gonno within the Accra Metropolis were selected for the study. These communities were selected because there is high concentration of e-waste activities. In addition, several studies have established that these communities have been affected by e-waste management practices (Oteng-Ababio et al., 2014; Amankwaa, 2014; Huang et al., 2014; Asante et al., 2012; Amoyaw-Osei et al., 2011; Brigden et al., 2008).

For the households, a total of 347 households with 95% confidence level were used for the study. With regards to e-waste workers, a total sample size of 48 was used for the study. It must be emphasized that the sample size for the e-waste workers was not calculated as the sample frame was not known. The researchers were able to collect data from only 48 people due to two main reasons. Firstly, because of the nature of their work, majority are not stationary as they normally scavenge for e-waste.

In addition, majority are migrants as observed by Oteng-Ababio (2010), whose stock of trade is to explore varied opportunities in the city. Secondly, the concept of saturation was detected during the data collection as the researchers realized that no new information was emerging. These reasons informed the decision to make use of 48 respondents. In view of the limited number of respondents, interpretation of the results at 95% precision must be done with caution. The institutional survey covered 11 institutions.

The study adopted both probability and non-probability sampling methods. These include systematic random sampling and purposive sampling techniques. The sample of institutions was purposive as the study targeted people who are policy makers or implementers as well as those involved in e-waste management activities.

Snowball sampling techniques was applied to select respondents of e-waste workers. With regards to households, the three selected communities were stratified into sub areas after which systematic random sampling involving picking a point within the community and moving at a regular interval were used.

In this case, the researchers selected a particular household for the study. In a situation where there were more than one household, accidental sampling was used to select one for the study. Again, in cases where selected household were unwilling to be part of the process, the researchers moved to the next household. After picking the initial household, the researchers picked every third house until the sample size was exhausted.

### Data collection

Three sets of questionnaires were developed for the households, e-waste workers and the institutions. This was guided by a 3-point Likert Scale with the following points: “critical”, “not sure” and “not critical” as scale. The questionnaires were self-administered.

## RESULTS

Respondents were asked to indicate the extent to which the eleven identified drivers and twelve barriers would facilitate or impede the adoption of effective e-waste management in Accra. Due to limited vocabulary of the local language which was used as a medium of communication for the data collection, a three-point ordinal scale with rating options of 1-not critical, 2-not sure and 3-critical was adopted. Two prong analyses were done. First, percentages for each driver in respect to the scale were calculated to find out the level of effects as perceived by respondents. In the second aspect, the score for “critical” responses were used to rank the drivers in order of importance for the three categories of respondents (Table 1).

Results of the data showed that regulatory framework was identified by households as the most critical issue to consider when adopting e-waste management option. The findings show that 87.0% of households, 95.8% of e-waste workers and all the respondents of the surveyed institutions consider this driver as critical. The findings suggest that this driver is the most critical factor among the eleven to consider when adopting e-waste management option. A possible explanation for the observed patterns may be attributed to the general perception that institution of regulatory controls and safety standards could help to regulate e-waste activities which is currently unregulated. This finding corroborates a study by Khetriwal et al. (2007), Keddee et al. (2013) and Nnorom and Osibajo (2009) who found that the success story of Extended Producer Responsibility (EPR) and the European Union (EU) directives on e-waste have been largely attributed to regulatory framework as the main driver. In addition, Phillips et al. (2002) identified regulatory framework among the main drivers of municipal solid waste management best practices in the United Kingdom (UK).

One striking observation is the assessment of “public health outcomes” especially by e-waste workers. Both the institutions and e-waste workers identified it as the most critical driver as they ranked it 1st while households ranked it 6th. This implies that respondents place high premium on public health over environmental outcomes. In terms of the level of effects, all the surveyed institutions (100%) and e-waste workers (100%) considered this driver as critical, while 83.3% of households indicated same. The finding affirms earlier one by Wilson (2007) who identified public health as an

**Table 1.** Ranking of key drivers by sample households, e-waste workers and institutions.

S/N	Key drivers	Households (n=347)		E-waste workers (n=48)		Institutions (n=11)	
		No.	Rank	No.	Rank	No.	Rank
1	Good policies and stricter legislation	299 (86.2)	3rd	45 (93.7)	3rd	11(100)	1st
2	Regulatory framework	302 (87.0)	1st	46 (95.8)	2nd	11(100)	1st
3	Education and public awareness	300 (86.4)	2nd	45 (93.7)	3rd	11(100)	1st
4	Environmental outcomes	277 (79.8)	7th	46 (95.8)	2nd	11(100)	1st
5	Public health outcomes	289 (83.3)	6th	48 (100)	1st	11(100)	1st
6	Efficient waste management institutions	292 (84.2)	5th	46 (95.8)	2nd	11(100)	1st
7	Socio-economic factors	223 (64.3)	10th	46 (95.8)	2nd	11(100)	1st
8	Potential market for recycled products	275 (79.2)	8th	46 (95.8)	2nd	11(100)	1st
9	Existence of the informal recycling sector	266 (76.6)	9th	42 (91.6)	5th	10 (90.9)	2nd
10	Community perception	180 (51.9)	11th	9 (18.7)	6th	10 (90.9)	2nd
11	Adequate infrastructure for collection, treatment and disposal	297 (85.6)	4th	43 (89.5)	4th	11(100)	1st

Source: Field survey (2015).

\*Figures in brackets are percentages.

important driver in Europe.

Education and public awareness on e-waste management is another factor which is deemed as critical when adopting e-waste management option. As shown in Table 1, 86.4% of households, 93.7% of e-waste workers as well as all the surveyed institutions (100%) evaluated this driver as critical. This driver is perceived by the surveyed institutions as one of the most important factor to consider in e-waste management as they ranked it 1st alongside eight other drivers. On the other hand, both households and e-waste workers ranked it 2nd. The finding supports Wilson (2007) who indicated that education and public awareness are among the main drivers of waste management best practices in the UK. Similarly, UNEP (2007), Savage et al. (2006) and Babu et al. (2007) observed that public awareness and knowledge of environmental and health impact of e-waste is critical for its management.

On driver number one, "good policies and stricter legislation", majority of households (86.2%), e-waste workers (93.7%) and all the institutions (100%) considered it critical. This finding supports the study by Wilson (2007), Kiddee et al. (2013) and Khetriwal et al. (2007) which showed that the driving factor for e-waste management best practices in most countries is the formulation of policies and institution of good legislation.

Finally, community perception was considered the least factor among the eleven drivers by respondents for the adoption of e-waste management option. The results showed that about half of households (51.9%), nearly one-fifth of e-waste workers (18.7%) and about nine-tenth of the surveyed institutions (90.9%) identified this driver as critical. However, majority of e-waste workers (77.1%)

evaluated community perception as not critical. Households ranked it 11th while e-waste workers and the institutions ranked it 6th and 2nd respectively which is last on their ranking.

The varied results highlight two key issues; first, varied perceptions about e-waste management and second how people perceived e-waste collection, treatment and disposal. For instance, if community perceives e-waste management as "resource management" (resource value of e-waste) but not as waste management or consider the management approach from the current paradigm shift from the conventional "end-of-pipe solution" to cradle-to-cradle, then, community perception would be seen as critical driver.

Additionally, societal held beliefs whether positive or negative about e-waste management appears to be critical in fashioning out e-waste management option (Oteng-Ababio, 2012c). However, the results suggest that majority of e-waste workers and some households are of the view that community perception, whether negative or positive, is not critical driver to affect the adoption of e-waste management option. The observed pattern confirms and validates the study of Wilson (2007) who found significant variations in what are perceived as the most important drivers between different spatial entities and also among stakeholders.

On the other hand, the results show that poor policy framework is perceived as the most critical barrier among the twelve to the adoption of e-waste management option. As shown in Table 2, 83.6% of households, 95.8% of e-waste workers and 100% of the institutions considered this barrier as critical. Interestingly, this barrier is ranked 1st by all the three categories of

**Table 2.** Ranking of key barriers by sampled households, e-waste workers and institutions.

S/N	Key Barriers	Households (n=347)		E-waste workers (n=48)		Institutions (n=11)	
		No.	Rank	No.	Rank	No.	Rank
1	Poor policy framework	290 (83.6)	1st	46 (95.8)	1st	11(100)	1st
2	Lack of or inadequate legal/regulatory framework	267(76.9)	8th	44 (91.6)	3rd	11(100)	1st
3	Low public education and awareness on e-waste management	285 (82.1)	2nd	42 (87.5)	4th	11(100)	1st
4	Unhealthy conditions of informal recycling	241 (69.4)	9th	11(22.9)	6th	9 (81.8)	3rd
5	Nonexistence of data on quantity of e-waste generated and disposed of annually	163 (47.0)	11th	13 (27.1)	5th	9 (81.8)	3rd
6	Weak waste institutions	275 (79.3)	4th	44 (91.6)	3rd	11(100)	1st
7	Unstable macro-economic environment	209 (60.2)	10th	44 (91.6)	3rd	11(100)	1st
8	Lack of involvement of stakeholders in decision making	268 (77.2)	7th	45 (93.7)	2nd	9 (81.8)	3rd
9	Limited capacity of state institutions to deal with e-waste	267 (76.9)	8th	45 (93.7)	2nd	10 (90.9)	2nd
10	Lack of or inadequate funding	283 (81.6)	3rd	45 (93.7)	2nd	11(100)	1st
11	Poor management arrangements and clearly defined responsibilities	274 (79.0)	5th	42 (87.5)	4th	10 (90.9)	2nd
12	High cost and inadequate management infrastructure	273 (78.7)	6th	44 (91.6)	3rd	10 (90.9)	2nd

Source: Field survey (2015).

\*Figures in brackets are percentages.

respondents (Table 2). The results affirm findings of an ILO (2011) study that identified poor policy framework as a major constraint to e-waste management in developing countries.

Similarly, “lack of or inadequate legal/regulatory framework” was considered by respondents as critical to affect the adoption of e-waste management. The study showed that majority of households (76.9%), e-waste workers (91.6%) and all the institutions surveyed (100%) considered this barrier as critical. The observed pattern is not unexpected as there is general perception that absence of legislation and regulatory regimes has contributed to the current e-waste management practices. The barrier is ranked 8th by households while e-waste workers and the institutions ranked it 5th and 1st respectively. The finding supports findings of a similar study by Kiddee et al. (2013) and Herat and Agamuthu (2012) who identified inadequate or absence of effective legislation as a major constraint to e-waste management in developing countries.

Additionally, low public education and awareness on e-waste management was perceived as a key barrier that could impede the adoption of e-waste management option in Accra. Households and the institutions ranked this barrier 2nd and 1st respectively, while e-waste workers ranked it 7th. The results showed that majority of households (82.1%), e-waste workers (87.5%) and the

institutions (100%) considered this barrier as critical. It appears the increasing awareness of the importance of education and awareness on best management practices account for the observed pattern. This finding corroborates Davis and Herat (2008) who identified low public awareness as key barrier which hinder the Australian local councils’ ability to encourage e-waste collection and recycling. Similarly, Hicks et al. (2005) indicated that lack of public awareness among e-waste collectors, recyclers and consumers has contributed to China’s difficulties in developing financial and environmentally sound e-waste management.

Another barrier that was assessed by respondents during the study was unhealthy condition of informal recycling. The study found that 69.4% of households and 81.8% of the institutions considered it as a critical barrier to the adoption of e-waste management. In contrast, 70.8% of e-waste workers said this barrier is not critical. The evaluation by the e-waste workers is not surprising because as Oteng-Ababio (2012b), Amankwaa (2014) and Oteng-Ababio and Amankwaa (2014) observed, e-waste management activities serve as livelihood for a substantial number of informal people.

Therefore, it would be suicidal for them to perceive this as impediment to the adoption of e-waste management. This barrier is ranked 9th by households while e-waste workers and the institutions ranked it 10<sup>th</sup> and 3rd

respectively as a barrier likely to affect the adoption of e-waste management option. This barrier was identified by Joseph (2007) and Hicks et al. (2005) as a critical hindrance to e-waste management in India and China respectively.

Finally, non-existence of data on quantity of e-waste generated and disposed of annually was perceived by respondents as the least critical barrier to the adoption of e-waste management. It was ranked 9th (last but one) by e-waste workers while households and the institutions ranked it 11th and 3rd respectively. The results suggest that respondents perceived the barrier as the least among the twelve that could impede the adoption of e-waste management option.

As shown in Table 2, majority of e-waste workers (64.6%) considered this barrier as not critical. In addition, 25.9% of households and 18.2% of the institutions assessed it as not critical. By inference, respondents do not consider data on quantity of e-waste generated and disposed of annually as important factor to determine the adoption of appropriate management option in terms of capacity and sustainability in event of waste diversion. However, 47% of households, 27.1% of e-waste and 81.8% of the institutions evaluated the barrier as critical. The finding contradicts results from study of ILO (2012) that identified this barrier as key factor to affect safe e-waste management.

## DISCUSSION

The study revealed that regulatory framework was identified as the most critical factor to consider in the adoption of e-waste management option. The results indicate that 87.0% of households, 95.8% of e-waste workers and 100% of the surveyed institutions perceived this driver as critical. This finding demonstrates the importance of regulatory framework as a key element of global best practices in sustainable e-waste management option as suggested in the literature. For instance, this finding is consistent with those from the previous studies that show that the success story of EPR and the EU Directives on e-waste have been attributed to regulatory framework as key driver (Kiddee et al., 2013; Nnorom and Osibajo, 2009; Cahill et al., 2011). Similarly, Phillips et al. (2002) identified regulatory framework among the key drivers of municipal solid waste best practices in the UK. It is apparent from this finding that, institution of regulatory framework could help to sanitize the e-waste sector. This is critical in the search of e-waste management option as currently e-waste collection and transport, treatment and disposal activities are unregulated resulting in poor management by the informal dismantlers.

Related to regulatory framework is good policies and stricter legislation as an important factor that will facilitate

the adoption of e-waste management option. The results show that 86.2% of households, 93.7% of e-waste workers and all the institutions surveyed perceived this driver as critical. This finding corroborates several studies which found that global best practices of e-waste management are driven by good policies and stricter legislation (Wilson, 2007; Kiddee, et al., 2013; Wagner, 2009). These studies have shown that e-waste management is driven by the EU's policy of EPR legislation and their Directives on Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances Directive (RoHS). For instance, Switzerland which is acknowledged as the pacesetter in e-waste management legislation introduced the Ordinance on "The Return, the Taking Back and Disposal of Electrical and Electronic Equipment" (ORDEEE) in 1998 by the Swiss Federal Office for the Environment (FOEN) to regulate e-waste management (Kiddee et al., 2013; Khetriwal et al., 2007; Nnorom and Osibanjo, 2008).

Similarly, Japan regulates e-waste by two main laws. These are the Specified Home Appliances Recycling (SHAR) Law promulgated in 1998 and entered into force in 2001 to take back four large household appliances: TV sets, refrigerators, air conditioners, washing machines and the Promotion of Effective Utilization of Resources (LPUR), while LPUR was passed to deal with personal computers and used batteries (Chug and Murakami-Suzuki, 2008; Ogushi and Kandikar, 2007). This finding is significant as it demonstrates the compelling need to formulate good policies that improve collection and transport, treatment and disposal standards. Similarly, enactment of specific legislation to govern e-waste collection and transport, treatment and disposal is also critical. By inference, the legislative framework will be very effective if it define roles and responsibilities of the major actors clearly as well as prescribe rewards and sanctions which can be enforced to the letter. This is very important because in the absence of legislation, removal of hazardous substances before processing may not be carried out. In addition, there is likelihood that, recyclers will focus on electronic and electrical appliances, and components that will yield maximum returns to their investment as observed by Wang et al. (2012) and Oteng-Ababio (2012c). This makes the formulation of good policies and enactment of stricter legislation, and their enforcement to promote compliance which has been the trump card of global best practices indispensable in the search for e-waste management option.

Another finding that was revealing was identification of public health outcomes by respondents as a critical driver for the adoption of e-waste management option. The results show that all the surveyed institutions (100%) and e-waste workers (100%) as well as 83.3% of households identified this driver as critical. This finding signifies respondents' awareness of the negative health effects of

e-waste management practices if it is not handled properly. This result confirms extensive literature review that has established that improper recycling by the informal sector has resulted in negative health effects on e-waste workers and people from the hosting as well as surrounding communities (Asante et al., 2012; Ha et al., 2009; Sepúlveda et al., 2010; Xing, et al., 2009; ILO, 2012). This finding clearly suggests that health implications of various management options are helpful and crucial for an environmentally sound management that will be socially acceptable and economically viable. This implies that policy makers and waste planners in their search for e-waste management option should, as a matter of priority, evaluate the possible health outcomes of different management scenarios to promote global best practices.

Moreover, education and public awareness on e-waste was also identified by respondents as equally important factor to consider when adopting e-waste management option. The results show that 86.4% of households, 93.7% of e-waste workers and 100% of the institutions perceived this driver as critical. This finding affirms earlier ones by UNEP (2007), Savage et al. (2006) and Babu et al. (2007) who indicated that public awareness and knowledge of environmental and health impact of e-waste is critical for its management. Similarly, this finding confirms and validates the findings by Wilson (2007) which identified education and public awareness among the main drivers of waste management best practices in the UK. These findings are indicative that successful management of e-waste that are in consonance with global best practices is contingent on public education and awareness on e-waste content, proper mechanism for collection and transport, appropriate treatment options and safe disposal practices. For instance, as indicated in the introduction, extensive literature review has found that e-waste contains both valuable and hazardous materials (Tsydenova and Bengtsson, 2011; Robinson, 2009; Babu et al., 2007; Lincoln et al., 2007). Therefore, public education and awareness on this contrasting threats and opportunities will be critical to guide material recovery to avoid adverse environmental and health effects (UNEP, 2012; Robinson, 2009).

In addition, extensive studies have documented adverse health impact of improper e-waste management practices (Kiddee et al., 2013; ILO, 2012; Asante et al., 2012; Lepawsky and McNabb, 2010; Osuagwu and Ikerionwu, 2010; Robinson, 2009; UNEP, 2007). Evidence from these studies makes this finding significant in the search for e-waste management option. By inference, public education and awareness on environmental and health impacts of e-waste and how to properly deal with it could be critical to reduce, if not eliminate, the adverse effects (Aizawa et al., 2008; Andreola et al., 2007). This implies that policy makers and waste planners in formulating e-waste policies and

strategies need to incorporate an educational component to raise awareness about the inherent hazardous nature of e-waste and best management practices in order to convince them to adopt safe collection, treatment and disposal methods.

Turning now to the barriers, the study found that poor policy framework is considered as the most critical barrier to the adoption of e-waste management option. The results show that 83.6% of households, 95.8% of e-waste workers and 100% of the institutions identified this barrier as critical. One striking observation is the ranking of the barrier by respondents. Interestingly, households, e-waste workers and the institutions ranked it as the most critical barrier to overcome in the adoption of e-waste management option. This finding suggests that respondents are aware of the effects of absence or poor policy framework on e-waste management. The finding also reflects the current management situation in the country which shows that there is no specific policy to govern e-waste collection and transport, treatment and safe disposal. These results corroborate previous studies that found poor policy framework as a major constraint to e-waste management in developing countries (ILO, 2012, Nnorom and Osibanjo, 2007).

Similarly, Oteng-Ababio (2012c) and Amoyaw-Osei et al. (2011) have demonstrated in their studies on e-waste management in the country that absence of specific policies to govern end-of-life management of obsolete electronic gadgets has resulted in the adoption of primitive practices by the informal recyclers and collectors. This revelation makes formulation of appropriate policy framework that will be inclusive and tailored along global best practices indispensable. The findings also suggest that the search for e-waste management option that will stand the test of time is contingent on the fashioning out a good policy framework that addresses the needs and aspirations of the major stakeholders.

Similarly, the findings of the study show that lack of, or, inadequate legal/regulatory framework could impede the adoption of e-waste management option. The results show that 76.9% of households, 91.6% of e-waste workers and all the institutions surveyed (100%) considered this barrier as critical. The finding highlights two key issues. First, the important role of legislation and regulatory framework in sustainable e-waste management and second, the adverse effects of absence or inadequate laws and appropriate regulatory framework to control, regulate and manage e-waste in an environmentally sound manner. This finding is consistent with many studies that have shown that e-waste management in an environmentally sound manner has been constrained by inadequate or absence of effective legislation in developing countries (Kiddee et al., 2013; Herat and Agamuthu, 2012; Nnorom and Osibanjo, 2008; Amoyaw-Osei et al., 2011, Oteng-Ababio, 2012c).

Consequently, nonexistence and laxity in the enforcement of existing regulations have resulted in the use of crude and inefficient recycling techniques by the informal recyclers to recover valuable materials without recourse to environmental and health safety measures (Oteng-Ababio and Amankwaa, 2014). The implication of this finding is significant as it suggests the institution of appropriate legal regime to manage e-waste.

Low public education and awareness on e-waste management was perceived by respondents as another critical factor that could hinder the adoption of e-waste management option. The study found that 82.1% of households, 87.5% of e-waste workers and 100% of the institutions perceived this barrier as critical. The finding could help to explain the general perception in the literature that poor knowledge and low level of public awareness of e-waste content as well as best management practices have invariably resulted in poor collection and transport, treatment and disposal. This finding corroborates earlier study by Davis and Herat (2008) who identified low public awareness as major barrier which impedes the Australian local councils' ability to encourage e-waste collection and recycling. Similarly, this finding confirms and validates Hicks et al. (2005) study that found that lack of public awareness among e-waste collectors, recyclers and consumers have contributed to China's difficulties in developing financial and environmentally sound e-waste management. This finding is significant as it suggests that public policy that incorporates education and awareness could play an important role in sustainable e-waste management in the search for management option.

Finally, one contrasting finding of the study by the three categories of respondents is the identification of unhealthy conditions of the informal recycling as a barrier to overcome in the adoption of e-waste management option. The results show that 69.4% of households and 81.8% of the institutions considered this barrier as critical factor that could constraint e-waste management. This corroborates other results from e-waste management studies in India and China that identified this barrier as a critical hindrance to e-waste management (Joseph, 2007; Hicks et al., 2005). This finding suggests that households and the institutions perceive the informal recycling activities as possible impediment to the formalization of the e-waste sector. By inference, abolishing or outlawing informal recycling will open the gateway for the establishment of formal recycling. Despite its policy significance, extensive literature has shown that the informal recycling is currently the dominant management option in many developing countries and emerging economies (Amoyaw-Osei et al., 2011; Oteng-Ababio, 2010; Oteng-Ababio et al., 2014; Laissaoui and Rochat, 2008; Waema and Mureithi, 2008).

For instance, studies by Oteng-Ababio et al. (2014), Amankwaa (2014) and Amoyaw-Osei et al. (2011) found

that about 95% of e-waste generated and collected annually in the country are processed by scavengers and dismantlers. On the contrary, 70.8% or majority of e-waste workers perceived this barrier as not critical. This finding is not unexpected since several studies have shown that e-waste collection and transport, treatment as well as various activities associated with the value chain serve as livelihood to a significant number of people including e-waste workers (Oteng-Ababio, 2012b; Amankwaa, 2014; Oteng Ababio et al., 2014; Sinha and Mahesh, 2013; Chaturvedi et al., 2011).

This dichotomy or contrasting findings is a challenge to policy makers and waste planners in the search for e-waste management option. In that, the informal sector is perceived as a threat on one hand and on the other hand as a potential. This implies that, policy formulation and management planning should be inclusive by harnessing the potentials of the informal recyclers and attempt to address their shortcomings. This should be seen as the best policy option since it can be inferred from the discussions that any attempt to exclude the informal sector would be counterproductive due to their unique role in collection and transport. Meanwhile, they have one of the best networks that are well-established for e-waste collection and transport which can be built upon.

This section sought to discuss the findings of the study. The study identified four critical factors that could facilitate the adoption of e-waste management option. These include regulatory framework, public health outcomes, education and awareness on e-waste management and good policies and stricter legislation. On the other hand, the results show that poor policy framework, lack of or inadequate legal/regulatory framework, low public education and awareness of e-waste management and unhealthy conditions of informal recycling as the four most critical barriers to overcome in the search of e-waste management option.

A close evaluation indicates the drivers and barriers are interrelated which has direct implications on environmental protection and waste management in general. This implies that the planning of efficient management option requires specific policies, regulations, environmental legislation and clearly articulated strategies for the realization of global best practices aim of environmentally sound manner.

## Conclusion

This study has identified critical drivers for and barriers to the adoption of household e-waste management option. The study findings were based on analysis of empirical data from 347 households, 48 e-waste workers and 11 institutions. The results showed that all the drivers were identified as very important to influence the adoption of e-waste management. However, regulatory framework,



public health outcomes and education and public awareness of e-waste management are perceived as the three most critical factors that could facilitate the adoption of e-waste management option, while community perception is considered as the least driver. Similarly, the 12 barriers were identified as critical to impede the adoption of e-waste management. The study found that poor policy framework, lack of, or inadequate legal/regulatory framework and low public education and awareness on e-waste management are considered as the most critical barriers, with non-existence of the quantity of e-waste generated and disposed of annually as the least critical factor perceived to constrain the adoption of e-waste management. Secondly, the findings also indicate that key stakeholders have different interests in e-waste management. This makes e-waste management difficult. Therefore, policy makers and waste planners should understand the nexus between consumers (households), e-waste workers and the institutions' interests. This will help in the formulation of appropriate policies and strategies that are more inclusive to address the needs and aspirations of the major actors. We conclude that these drivers and barriers need to be considered in any e-waste management to ensure environmentally sound management practices.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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