Climate Change Effects and Implications for Wastewater Treatment Options in Ghana

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Abstract

Climate change is a major global challenge in the 21st Century, with Africa as one of the most vulnerable regions to its predicted impacts due to low adaptive capacity. In literature, the effects of climate change on water availability are well documented with projections indicating an increase in water stress populations due to decreasing water availability, ultimately resulting in increasing wastewater reuse for West Africa Region. Climate resilient wastewater treatment options must be identified to protect human health and environment. The aim of this paper is to assess the possible implications of climate change on wastewater treatment options in Ghana, West Africa. Temperature, rainfall and evapotranspiration trends are analyzed from meteorological data for the cities of Accra and Tema, over the last five decades stretching from years 1963 to 2013. The long-term changes in all three climatic parameters have been assessed by linear trend analysis. Mann-Kendall trend test is used to confirm the increasing trend in mean annual temperature and evapotranspiration and decreasing trend in rainfall for both cities. Mean annual temperature and evapotranspiration for Accra and Tema increased by 0.65°C and 1.3°C, and 11.8mm and 5.2mm respectively, with rainfall decreasing by 171.4mm and 83.4mm respectively. Projections were made for the climatic variables for the next 50 years, using 2010 as the base year. Applying multi-criteria analysis to compare the various treatment options in use in Ghana resulted in the activated sludge as the most climate resilient wastewater treatment option. Though the activated sludge process is not a first choice option for developing countries due to its high energy, capital and skills requirements, the results of this study indicate a need for its modification to make it viable and sustainable for developing countries in the face of climate change.

Keywords: Climate change, Trend analysis, Wastewater treatment options, Ghana.

1. Introduction

Changes in the climate system due to anthropogenic emission of long-lived greenhouse gases (GHGs) is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC 2007). Global average sea level rose at an average rate of 1.8mm per year over 1961 to 2003 and at an average rate of about 3.1mm per year from 1993 to 2003, while temperature increase is widespread over the globe and is greater at higher northern latitudes (IPCC 2007). In West Africa, a decline in annual rainfall has been observed since the end of the 1960s, with a decrease of 20 to 40% noted between the periods 1931- 1960 and 1968-1990 (IPCC 2007; Nicholson 2000). Several General Climate Models (GCMs) predict the continuation of these trends into the near future and their subsequent effects at global, continental and regional levels (Müller 2009). Studies undertaken by the World Bank on the Economics of Adaptation to Climate Change (looking at the 2010-2050 period) and the 2000 United Nations Development Program (UNDP) Climate Profile of Ghana (looking at the 2060-2090 period) have revealed overall climate trends and their future projections for Ghana. Mean annual temperature is projected to increase by 1.0 to 3.0°C by the 2060s, and 1.5 to 5.2°C by the 2090s. The projected rate of warming is most rapid in the northern inland regions of Ghana. Total annual rainfall is projected to decline by 1.1%, and 20.5% in 2020 and 2080, respectively, with early termination of rainfall in the transitional zone, and the likely conversion of the current bi-modal regime to a uni-modal one (World Bank Group 2011).

Evidently from these projections, climate change has the potential to impose additional pressures on water availability, water accessibility and water demand in Africa. Overall water demand in Africa is expected to more than double in the first half of 21st century, increasing water stress populations i.e. there is less than1000m^3/yr/capita available and hence more wastewater reuse (Tadesse 2010; Vörösmarty 2005). About 25% of Africa's population (about 200 million people) currently experience water stress, (Vörösmarty 2005). Even in the absence of climate change, present population trends and patterns of water use indicate that more African countries will exceed the limits of their "economically usable, land-based water resources before 2025" (Müller

2009). In some assessments, the population at risk of increased water stress in Africa, for the full range of Special Report on Emissions Scenarios (SRES) scenarios, is projected to be 75-250 million and 350-600 million people by the 2020s and 2050s, respectively (Arnell 2004) .

Most climate change studies however focus on impacts on water resources, ecosystems, disease, agriculture and food security with little mention of impacts on wastewater treatment options, especially in Sub-Saharan Africa, not withstanding the fact that about 40% of its population lacked access to improved sources of drinking water as at 2011 (WHO 2013). The discharge of untreated or improperly treated wastewater, irrespective of its source, into the environment can impact strongly on aquatic ecosystems, through eutrophication. In addition, where such watercourses are utilized by humans, either as a source of potable water or for washing or bathing, would present potential risks of the transmission of a large number of water-related diseases (Horan 2003). Between 20-30 different infections are associated with water usage, namely through water-borne, water-based, water-washed or water-related vectors, with the number of people world-wide suffering from these diseases estimated by the World Health Organization at 1.25 billion, with majority in developing countries (Horan 2003). Furthermore, reduced precipitation coupled with a decrease in water availability limits dilution effects and forces communities to use contaminated water resulting in a significant increase in water-borne illnesses (Hashizume et al. 2007).

In Ghana, secondary methods of wastewater treatment have been employed over the years with waste stabilization ponds, constructed wetlands, trickling filtration and activated sludge being the main ones (Adu-ahyiah & Anku 2001; Asimeng 2012). Waste stabilization ponds are mainly shallow man-made basins comprising a single or several series of anaerobic, facultative or maturation ponds, with primary treatment taking place in the anaerobic pond, secondary treatment in the facultative pond and tertiary treatment, where necessary, in the maturation pond (Mara et al. 2004). Constructed wetlands for wastewater treatment involve the use of engineered systems that are designed and constructed to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated microorganisms to remove contaminants from wastewater effluents (Kivaisi 2001; Mara 2004). The trickling filtration method consists of a filter bed of highly permeable media to which microorganisms are attached and sewage is intermittently sprinkled. Oxygen is provided by the intermittent working of the filter, allowing bacteria to oxidize the sewage producing effluent in the form of water, new cell and gases. The activated sludge, like the trickling filter, is an aerobic process involving the use of microorganism to oxidize the sewage in an aeration tank with solids separation occurring in a sedimentation tank; the difference between them being that the activated sludge is a suspended growth process, while the trickling filter is an attached growth process (Horan 2003).

As one of the most vulnerable regions in the world to the projected impacts of climate change due to its low adaptive capacity, Africa faces many challenges. It contributes little to GHGs emissions, but will seriously suffer from the undesirable impacts of climate change (Müller 2009; Tadesse 2010). Therefore the need for research to improve on adaptive capacity and hence reduce vulnerability, especially in the area of wastewater treatment, cannot be over-emphasized. Long term trend analysis of atmospheric variables such as temperature, rainfall and evapotranspiration have been used extensively [e.g. rainfall by (Dore 2005); temperature by (Kruger & Shongwe 2004; Kusangaya et al. 2013; Mendoza & Martins 2006); evaporation (and soil moisture) by (Malisawa & Rautenbach 2012) as proxies for detecting changes in climate. This paper assesses the potential impacts of climate change on wastewater treatment options in Ghana. Mann-Kendall test and linear trend analyses are used to detect trends for three meteorological variables: rainfall, temperature and evapotranspiration for the last five decades. Predictions were then made for the next five decades, and multi-criteria analysis used to compare the various wastewater treatment methods employed in Ghana and the most climate resilient treatment option identified.

2. Data and Methodology

2.1 Data

Monthly rainfall, maximum temperature and evapotranspiration data (for 50 years from 1963 to 2013) for two cities, Accra and Tema, was collected from the Meteorological Services Department (MSD) of Ghana. The data was processed and the mean annual values for all the parameters calculated.

2.2 Methodology

2.2.1 Trend Analysis

Trend detection in hydroclimatic research is frequently conducted by means of the Mann–Kendall (MK) nonparametric test (Kendall 1975; Mann 1945). MK test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series (Bawden et al. 2014). There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al. 2011). Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H1, which assumes that there is a trend (Onoz & Bayazit 2012). Where the computed p-value is lower than alpha at a chosen significance level, then the null hypothesis H0 is rejected. A positive (negative) value indicates an upward (downward) trend (Drapela and Drapelova 2011). Another statistic obtained on running the MK test is Kendall's tau, which is a measure of correlation and therefore measures the strength of the relationship between the two variables. Kendall's tau will take values between ±1 and +1, with a positive correlation indicating that the ranks of both variables increase together whilst a negative correlation indicates that as the rank of one variable increases, the other decreases. The Man-Kendall test was therefore adopted for the trend analysis using Addinsoft's XLSTAT, 2014. The null hypothesis is tested at 5% significance level for all the parameters. Linear trend lines were also plotted for each of the data sets using EXCEL 2013 to compare the results of the Man-Kendall test and predict also the trends for the next 50 years (2010 to 2060).

2.2.2 Multi-criteria Analysis

Multi-criteria analysis (MCA) using the performance matrix technique was subsequently used to compare the various treatment options. The performance matrix is a direct scoring method which does not involve weighting (Mendoza & Martins 2006; Department for Communities and Local Government 2009). This method asks decision-makers to specify numerical, 'bullet point' scores or color coding for the expected performance of decision alternatives measured against multiple objectives. Each row describes one of the options that are being considered, each column corresponds to a criterion, or 'performance dimension', which is considered important to the comparison of the different options, and the entries in the body of the matrix assess how well each option performs with respect to each of the criteria (Department for Communities and Local Government 2009). Then, all the points obtained for all the criteria for each of the alternatives are summed to produce a ranking of the alternatives (Suedel et al. 2009). Despite its limitation in terms of biases (Kiker et al. 2005), this method is frequently applied to evaluate environmental problems because it is the easiest and simplest method to use (Mendoza & Martins 2006). Effects of high temperature and evapotranspiration, and low rainfall were used as criteria for assessing the various wastewater treatment options (constructed wetlands, waste stabilization ponds, trickling filtration and activated sludge). 'Bullet points', ● (best) and ●●●● (worst) were assigned for each criterion for each of the treatment options.

3. Results and Discussion

3.1 Trend Analysis

Results of the MK trend detection test are summarized in Table 1. All the p-values were lower than the significance level alpha =0.05 (one tailed test). Hence the null hypotheses (H0) for all the climatic parameters were rejected and the alternate hypotheses (H1) accepted, indicating a trend for each of them. The exact p-value could not be computed for values <0.0001, hence an approximation was used. But an exact method was used to compute p-values of 0.000 and above.

Table 1. Results of Mann-Kendall Test for Meteorological Parameters.

Parameter	**Mann-Kendall Test**					
	Sen's Slope	**Mann-Kendall Statistic (S)**	**Kendall's Tau**	**p-value (one tailed test)**	**Alpha**	**Test Interpretation**
Temperature (Tema)	0.025	579,000	0.554	< 0.0001	0.05	H_0 Rejected
Temperature (Accra)	0.016	525,000	0.430	<0.0001	0.05	H_0 Rejected
Rainfall (Tema)	-0.327	-48,000	-0.727	0.000	0.05	H_0 Rejected
Rainfall (Accra)	-3.166	-63,000	-0.700	0.000	0.05	H_0 Rejected
Evapotranspiration (Tema)	0.148	166,000	0.249	0.015	0.05	H_0 Rejected
Evapotranspiration (Accra)	0.273	695,000	0.524	<0.0001	0.05	H_0 Rejected

The value of the Kendall's tau was positive for temperature and evapotranspiration for both Tema and Accra, indicating an increase in these parameters with time. Temperature (Tema) and Evapotranspiration (Accra) had Kendall's tau values of 0.554 and 0.524 respectively, indicating a very strong relationship (Table 1). Tabari et al. (2011) illustrated the relationship between temperature and evapotranspiration for arid and semi-arid climates. According to results obtained by them, increasing air temperature by 5%, 10% and 20% increased reference evapotranspiration (ETo) by about 2%, 3.7% and 7.4% respectively. The results of this study indicate that temperature may not be the only condition driving evapotranspiration. Accra, for example, though recorded a temperature increase of 0.65°C, had the highest evapotranspiration increase of 11.8mm more than doubling that of Tema for the same period, even though Tema had an increase in temperature of about 1.3°C.

Rainfall for both Accra and Tema however had negative values for Kendall's tau, implying a decrease in that parameter with time. This negative correlation was however very strong for both places (0.727 and 0.700 respectively). Temperature and evapotranspiration for both places had positive Sen's slope values, with the lowest occurring for temperature (Accra).

Results of line graphs and linear trend lines plotted for all parameters are showed in Figure 1 below. The slopes of the trend lines, obtained from the equations, were similar to the Sen's slopes values obtained from the MK test, with temperature and evapotranspiration increasing while rainfall decreased with time. For Accra, rainfall decreased from an annual average of 852.2mm in 1965 to 680.8mm in 2010, a drop of about 171.4mm for the 45 years period.

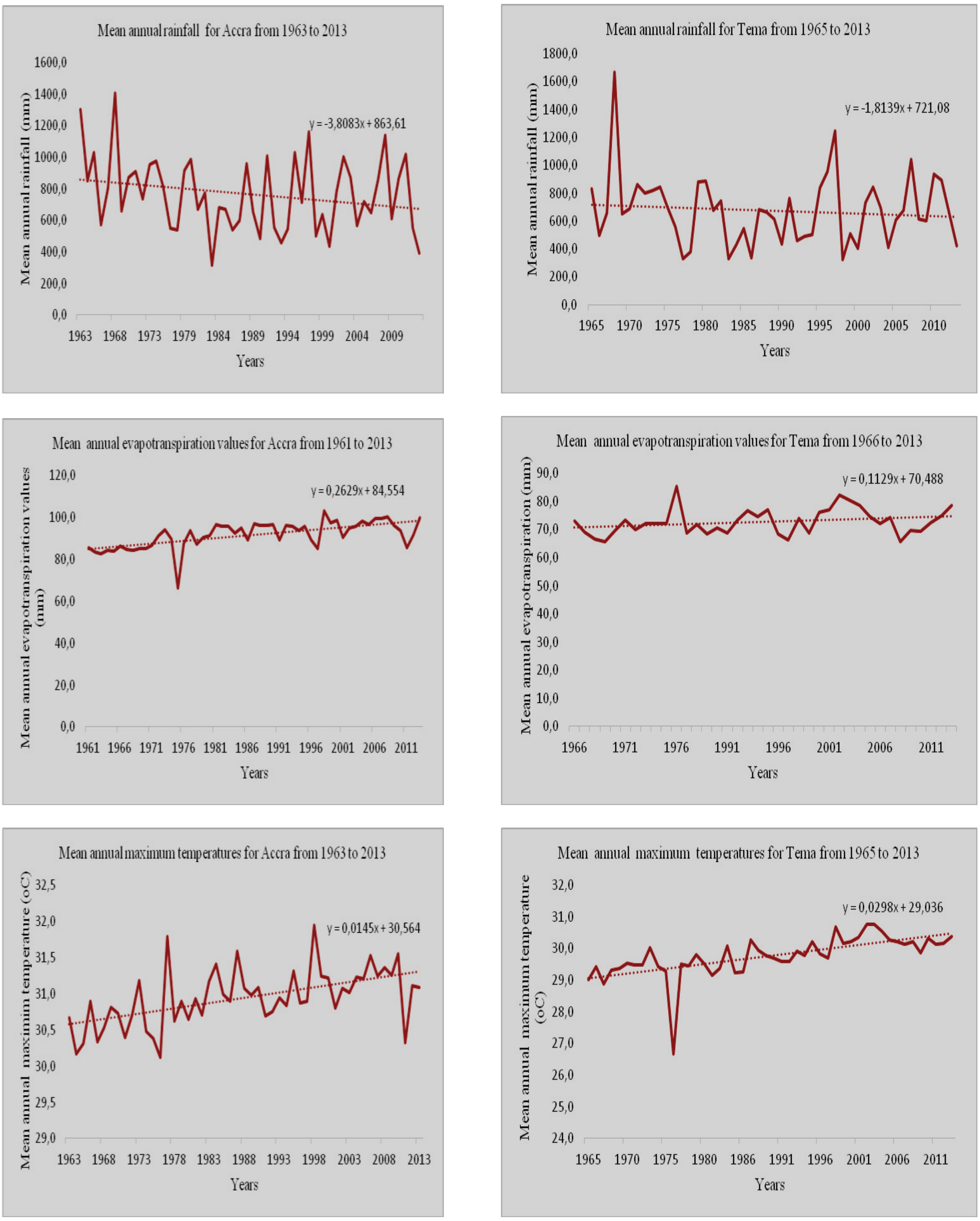

Figure 1. Line Graphs with Trend Lines for Mean Annual Rainfall, Evapotranspiration and Temperature for Accra and Tema

Tema saw a decrease from 721.1 to 637.6mm, a drop of 83.4mm within the same period. Nair et al. (2014) in their study on rainfall trends in Kerala, India also observed a decreasing trend over the last 100 years in almost every district. SRES A1B emissions scenario and for 2080-2099, mean annual rainfall is very likely to decrease along the Mediterranean coast (by 20%), extending into the northern Sahara and along the west coast to 15^{o}N (Boko et al. 2007).

Temperature for the same period for Accra increased by 0.65^{o}C while Tema increased by 1.3^{o}C, with evapotranspiration also increasing by 11.8 and 5.2mm respectively for the same time period (Table 1). Analyses of both remote sensing derived and observed temperature records in southern Africa agree that over the last decades the region has been experiencing a warming trend. Several scholars, including (Kruger & Shongwe 2004; Kusangaya et al. 2013) and New et al. (2006) analyzed observed temperature trends. The basic conclusion drawn from these studies is that temperatures are rising, with minimum temperatures rising faster than maximum temperatures. Hulmeet al. (2001) undertook a comprehensive comparison of results from seven General Climate Models (GCMs) under four SRES scenarios on the African continent. They calculated an increase in surface temperature of between 0.2 and 0.5^{o}C per decade. This compares well with results of current study. The overall result has thus been a warming trend (Kusangaya et al. 2013).

Table 2. Summary of Meteorological Parameters Values for Accra and Tema (1965-2060)

Parameter	**1965**		**2010**		**2013**		**2060**	
	Accra	**Tema**	**Accra**	**Tema**	**Accra**	**Tema**	**Accra**	**Tema**
Rainfall (mm)	852.19	721.08	680.80	637.64	669.39	632.20	490.40	546.95
Evapotranspiration (mm)	85.87	70.38	97.70	75.57	98.49	75.91	110.84	81.20
Temperature (^{o}C)	30.61	29.04	31.26	30.41	31.30	30.50	31.99	31.90

The projections of these results for the period 2060 are also summarized in Table 2 above. The results alluded to a continuation of the observed trends; rising temperatures and evapotranspiration and declining precipitation. However, Hendrix & Glaser (2007) assessing the outlook for the future based on an analysis of simulated changes in precipitation means and variability found that overall levels of precipitation are expected to increase in the next 100 years in Western Africa. This prediction is at variance with the current findings, and it also highlights the limitations inherent in the use of GCMs, whereby local conditions which sometimes might be very diverse are often overlooked (Müller 2009). Hulme et al. (2001) further articulate this fact by stating that current generation GCMs do a poor job of replicating El Niño Southern Oscillation (ENSO) variability, simulations of interannual variability in African precipitation are suspect. Ghana’s climate is tropical and strongly influenced by ENSO (World Bank Group 2011).

3.2 Multi-criteria Analysis

Effects of various climatic variables on wastewater treatment have been well document in literature (Leitão et al. 2006; Robert 2001; Wett & Buchauer 2002; Yuan et al. 2013). Results of multi-criteria analysis gave the activated sludge method as the most climate resilient option for wastewater treatment under the changing climatic conditions (Table 3).

Table 3. Performance Matrix Used for Comparison of Treatment Methods

Treatment Option	**Criteria**			**Rank**
	High Temperature	**Low Rainfall**	**High Evapotranspiration**	
Constructed Wetlands	●●●●	●●●●	●●●●	●●●●●●●●●●●●
Waste Stabilization Ponds	●●●	●●●	●●	●●●●●●●●
Trickling Filtration	●●	●●	●●●	●●●●●●●
Activated Sludge	●	●	●	●●●

An increase in temperature results in an increase in biochemical activity, with responses in wetlands much greater to changes at the lower end of the temperature scale (<15^{o}C) than at the optimal range (20-35^{o}C). Projections from this study indicate an average temperature of 32^{o}C by 2060 (Table 2). Most filamentous bacteria are mesophilic hence their growth increases up to temperatures of 35^{o}C and ceasing at about 40^{o}C (Jenkins et al. 2004). The comparative advantage of the activated sludge over the trickling filtration is because of its low evapotranspiration. Increasing temperature reduces the amount of dissolved oxygen, and so without an aeration mechanism, aerobic processes like those occurring in waste stabilization ponds will be affected. The major disadvantage of the constructed wetlands and waste stabilization ponds is their high evapotranspiration rate due to large surface area requirements and presence of plants. There exist a direct relationship between evapotranspiration and temperature (Huo et al. 2013).

4. Conclusion and Recommendations

An insight is given to the possible impacts of climate change on wastewater treatment options in Ghana, based on analysis of meteorological variables for the past five decades. Mean annual temperature and evapotranspiration showed significant increasing trends while decreasing trend was found for rainfall for both cities. Temperature increased by 0.65^{o}C and 1.3^{o}C while rainfall reduced by 171.4mm and 83.4mm for cities of Accra and Tema respectively. A comparison of the various wastewater treatment options, based on projections for these meteorological variables for the next 50 years yielded the activated sludge process as the most climate resilient option.

The results of this study in general, point towards a dryer situation for the future, with a possible increase in wastewater reuse due to decreasing water availability. Also other conditions besides temperature may be driving evapotranspiration. This finding is helpful for water management policy planning in terms of implementation of water efficient systems for municipal and agricultural purposes, as part of climate change mitigation and adaptation strategies. Considering that waste stabilization ponds are the most preferred wastewater treatment option for developing countries, the findings of this study suggest modifications to the conventional activated sludge process to reduce its energy, capital and skills requirements, to make it a viable and sustainable option for developing countries, especially Ghana.

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