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African Journal of Environmental Science and Technology

Full Length Research Paper

Bushfires spread modelling over Malea in Northeastern Guinea

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Bush fires are increasingly becoming a threat to Guinean ecosystems and their understanding is a big challenge to scientists and environmental managers. Using the FARSITE model (Fire Area Simulator), this paper presents the prediction of the spread and characteristics of bush fires in the savannahs of North-eastern Guinea, specifically in Malea/Siguiri prefecture. Inputs, vegetation and topography dataset from satellite imagery (30 m resolution, Landsat and SRTM respectively) as well as *in-situ* meteorological data (wind, temperature and humidity) were used. These data obtained from the boundaries of the area of study were prepared using Geographic Information System (GIS). The burning time and the ignition points were fixed while admitting 3 scenarios: spread of fire in a plain without wind; spread on hills without wind effect and spread with wind effect. The results show that, in these savannahs, the intensity of the fire lines can reach 4133,3 KW/m under the effect of winds. Without winds, a decrease of 69% over plains and 68% over hills is noted. The amount of heat released could go up to 38000 KJ/m^2 with the wind effect. While, without the wind effect a decrease of 10 and 9% over the plains and hills is observed respectively. Eventually, the speed of propagation reaches 8 m/min (0.5 km/h), but without the wind, it would decrease up to 73 and 61% over plains and hills, respectively. This study could be improved to serve as a decision support tool for the management of ecosystems North-eastern Guinea.

Key words: Fire area, prediction modeling, simulator, ecosystem managers, Guinea.

INTRODUCTION

The study of bush fires is more and more concern in the world because of its many environmental and social consequences. In Guinea, the sharp decline in forests due to anthropogenic pressure and climatic variability raises concerns in terms of understanding fires that threaten the environment. The southern and southwestern parts of Guinea are so-called forest areas, while the north and north-east are practically savannah regions that are

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regularly covered by fires for the benefit of hunting and agropastoral activities.

Bushfires, apart from their harmful effects on ecosystems, are an important source of greenhouse gas emissions and aerosols in the atmosphere (Trabaud, 1974; Monnier, 1981; Achard et al., 2002). These emissions strongly affect the climate, the earth's radiation balance, air quality, human health and the economy (Chandler, et al., 1983). These are concerns for many researchers, in the fields of climatology, risk prevention and forest management (Breton et al., 2008; Thonat, 2013). Previous study in the field of fire observation has already greatly contributed to the understanding of their spatio-temporal distribution and their recurrence in the North-east of Guinea, more specifically in the county of Siguiri (Millimono et al., 2017), to the estimation of burned areas and their predictability (Barry et al., 2015; 2018).

Siguiri, a county located in the north-east of Guinea bordering Mali, is a gold producing area where activities requiring the use of fire (cleaning of gold mining areas, subsistence-oriented farming and livestock, coal production, etc.) are various. Its vegetation is mostly grassy and shrubby with rare forest galleries. During the dry season (November to May), a fire breaks out on such a landscape, stirred up by the wind can consume little grass, brush, branches.... But which way will it go? How fast will it spread depending on the land, wind speed and direction, type of vegetation? How much heat would it release on average? This is what forest managers and firefighters are keen to know to organize prevention and control more effectively. Nowadays, computer simulation of fire could not only make it possible to know approximately the evolution of a fire in progress in order to recommend the appropriate method and means for its extinction; but could also be used in preventive development plans to reduce the risks of fire damage (Achard et al., 2002; Forghani, 2007). The illustrations are better in relation to the texts as part of the sensitization on bushfires.

This article does not intend to build a model from scratch; to critically review existing models or provide an exhaustive list of all past work, since many works have been done in these issues (Pastor et al., 2003; Sullivan, 2008; Mohamed, 2013). In this paper we rather try to highlight the usefulness of the FARSITE model for predicting fire behavior in northeastern Guinea, especially over Malea, so as to produce useful information for environmental protection.

MATERIALS AND METHODS

The FARSITE model used is a deterministic two-dimensional fire growth model that allows explicit spatio-temporal representation at the landscape scale (Rothermel, 1972; Finney, 1998; 2004). FARSITE uses the Rothermel model, which has been developed from a solid theoretical basis to make its application as broad as possible. This basis was provided by Frandsen (1971) and Rothermel (1972), who applied the principle of energy conservation to a unit volume of fuel upstream of an advancing fire in a homogeneous fuel bed. Their analyses led to the following:

$$\boldsymbol{R} = \frac{\boldsymbol{I_{xig}} + \int_{-\infty}^{0} (\frac{\partial I}{\partial Z})_{zc}\, dx}{\rho b_e Q_{ig}} \tag{1}$$

Where: ***R*** is the quasi-stable spread rate (ft.mn^{-1} with ft=0.3048m), ***Ixig*** is the horizontal heat flux absorbed by a unit volume of fuel at the time of ignition (B.t.u/ft^2.mn with *B.t.u* =1055.055J), ρ_{be}, effective bulk density (amount of fuel per unit volume of fuel bed at ignition in front of fire), expressed in lb/ft^3 with lb=1/2.20462 kg, ***Qij***, pre-ignition heat (amount of heat required to ignite a unit of fuel) expressed in Btu/lb, $(\frac{\partial I}{\partial Z})_{zc}$the gradient of vertical intensity evaluated on a plane at a constant depth (Btu/ft^2.mn), ***zc*** = constant fuel bed depth. The horizontal and vertical coordinates are ***x*** and ***z*** respectively.

The heat received for ignition depends on the ignition temperature, the moisture content of the fuel and the amount of fuel used in the ignition process. After ignition, the heat propagation flux, which is the numerator of equation (1), is written.

$$\mathbf{I_p} = \mathbf{I_{xig}} + \int_{-\infty}^{0} (\frac{\partial \mathbf{I_z}}{\partial \mathbf{Z}})_{\mathbf{zc}}\, \mathbf{dx} \tag{2}$$

it is expressed in Btu/ft^2.mn

The propagation flow is composed of two terms: the horizontal flow and the vertical flow gradient. Assuming that the vertical flow is low for windless lights, and negligible slopes, we can write:

$$I_p = I_{xig} = Ip_0 \tag{3}$$

This leads to $\boldsymbol{R=R_0}$ and where from Equation 1 it comes from:

$$\boldsymbol{I_p} = (\boldsymbol{I_p})_0 = \boldsymbol{R_0 \rho_b\, \varepsilon Q_{ig}} \tag{4}$$

In the model, $(\boldsymbol{I_p})_0$ is the component of the basic heat flux to which all the additional effects of wind and slope are associated. Wind and slope change the flow of heat propagation by exposing the potential fuel to the effects of convection and heat radiation.

Given the complications of finding an analytical solution to the propagation equations due to the existence of some unknown parameters, Rothermel introduced the experimental and analytical formulation obtained in the laboratory as follows:

$$\boldsymbol{I_p} = (\boldsymbol{I_p})_0\, (1 + \emptyset_w + \emptyset_s) \tag{5}$$

where $\emptyset_w$ and $\emptyset_s$ are the additional propagation flows produced by wind and slope. The equation for the propagation rate provided by Frandsen then takes the following form:

$$\mathbf{R} = \frac{(\mathbf{I_p})_0\, (1 + \emptyset_w + \emptyset_s)}{\rho_b \varepsilon Q_{ig}} \tag{6}$$

with $\boldsymbol{\varepsilon} = \frac{\rho_{be}}{\rho_b}$ and $\boldsymbol{\varepsilon} = \mathbf{e}^{\left(\frac{-138}{\sigma}\right)}$; $\boldsymbol{\sigma} = \frac{4}{d}$ ***d*** being the diameter of the fuel strand.

Rothermel (1972: 33) placed an upper limit on the wind factor. What Albini (1976) called “maximum reliable wind” is a function of reaction intensity (IR). Rate of spread is modeled as constant for wind speeds greater than that value. The wind limit is defined as the point where:

$$U > 0.9I_R \quad (7)$$

Andrews et al. (2013) corrected an error in an assumption to give the wind limit as:

$$U = 96.8I_R^{1/3} \quad (8)$$

To introduce wind and slope into the model, it is necessary to evaluate the coefficients $\emptyset_w$ and $\emptyset_s$. Assuming $\emptyset_s$= 0 in Equation 5, it comes:

$$\emptyset_w = \frac{I_p}{(I_p)_0} - 1 \quad (9)$$

If the fuel parameters in Equation 3 are assumed to be constant, the propagation of the flux is proportional to the propagation rate and Equation 7 becomes:

$$\emptyset_w = \frac{R_w}{R_0} - 1 \quad (10)$$

where $\boldsymbol{R_w}$ is the wind propagation rate.

In a similar way,

$$\emptyset_s = \frac{R_s}{R_0} - 1 \quad (11)$$

where ***Rs*** is the propagation rate under the effect of slopes. The reaction intensity of a surface fire refers to the production of thermal energy (the rate of energy released per unit area) at the inflamed front. It was defined by Rothermel and later redesigned by Wilson (Wilson, 1980):

$$\mathbf{I_R} = (\tfrac{\mathbf{1}}{\mathbf{60}})\boldsymbol{\Gamma}'\mathbf{W_n h \eta_M \eta_S} \quad (12)$$

Where: $\boldsymbol{I_R}$ = reaction current (kW / m^2) ; Γ'= optimum reaction speed (min-1)
Wn = Net fuel load (kg / m^2) ; h = Fuel heat content (kJ/kg);
η_M = Humidity damping coefficient (0 to 1) η_S = Mineral damping coefficient (0 to 1).

Residence Time Residence time (***t***) is the length of time that it takes the fire front to pass a given point. Anderson (1982) found that an approximation of the burning time of burning fuel particles in a uniform fuel system can be calculated from the size of the fuel particles.

$$\boldsymbol{t = 8d} \quad (13)$$

Rothermel's surface fire spread model uses surface-area-to-volume ratio (σ) as a measure of fuel particle size. The relationship to diameter is $\boldsymbol{\sigma = \frac{48}{d}}$ and residence time is then:

$$\boldsymbol{t = \frac{384}{\sigma}} \quad (14)$$

Heat per unit area (*HPA*) is the product of the reaction intensity (I_R) and the time that the area is in the flaming zone, as indicated by the residence time (*t*). Reaction intensity is the rate of energy release per unit area within the flaming front (Btu/ft2/min). Heat per unit area is the amount of heat energy release per unit area within the flaming front (Btu/ft2):

$$H_{PA} = I_R.t \quad (15)$$

Albini (1976) defined relationships to use Rothermel's spread model to find fireline intensity.

$$I_B = FLI = H_A.R \quad (16)$$

Flame length is calculated from fireline intensity according to Byram's equation (Brown and Davis, 1973: 175):

$$FML = 0.45I_B^{0.46} \quad (17)$$

FARSITE predicts the rate of spread and intensity of fire reaction in a continuous layer of fuel adjacent to the ground. It uses a fuel input model that describes the fuel types and physical characteristics to predict ignition, a topography file and weather file that are factors influencing propagation (Table 1). The landscape groups the mandatory model parameters while the climate forms the group of model forcing parameters also known as optional parameters (Stratton, 2009). The FARSITE outputs on which we based the fire behavior analysis are: Time of Arrival (.TOA in hours); Fire line Intensity (.FLI in kW/m); Flame Length (.FML in m) ; velocity or Rate of Spread (.ROS in m/min) ; heat per unit area (.HPA in kJ/m^2) ; the Reaction Intensity (.RCI in kW/m^2); the Spread Direction (.SDR in degrees azimuth) and the Crown- No Crown (.CFR The units are: 1 for a surface light, 2 for a passive top light, and 3 for an active top light).

FARSITE, like most fire forecasting models, has been calibrated and validated in the United State in the different ecosystems of the Mediterranean basin (Moretti, 2015). Its operation requires the use of a Geographic Information System (GIS).

In the "FARSITE" fire spread model, standard fuel models or custom fuel models can be used. The custom fuel model is applied when the standard fuel model does not match the vegetation characteristics in a study area. The characteristics of the fuels flammability are incorporated in the simulator for standard fuel models between 1 and 13, and only the weather parameters and the topography vary significantly from one medium to the other, thus influencing the spread and characteristics of fire. Any vegetation with approximately the same characteristics as these where model was developed may have nearest neighbor fuel numbers (Anderson, 1982). The comparison is made according to the type of vegetation. For fuel totally different from the standard fuel model, a custom fuel model is recommended to hope to produce good simulation. The choice of Maléa takes into account these criteria. In this study, the standard fuel model was selected for two reasons:

(i) The vegetation of the selected Malea area meets Anderson's fuel classification criteria (Anderson, 1982).
(ii) The implementation of a customized fuel model requires large resources for the detailed study of vegetation types (case of plant formations in central, south-eastern and south-western Guinea). We therefore focused on this Siguiri area for this first stage of our fire behavior prediction.

Regarding the relief, Siguiri is an area with plain, plateau and hills. According to meteoblue link (https://www.meteoblue.com), the temperature maxima in this area on oscillate between 29 and 40° and the minima between 20 and 26° depending on the month. The wind speed at 12 m switches between 0 and 91 km / h, the amount of rainfall in the area varies between 0 and 100 mm / month.

Table 1. FARSITE input parameter functions.

Input type	Data Entry	Function
Landscape	Elevation	For adiabatic temperature and humidity control
	Slope	For the calculation of direct effects on fire spread
	Aspect	Combination with slope and latitude determines the angle of incident solar radiation
	Fuel Model	Provides a physical description of the surface fuel
	Forest cover	Determines the average shading of surface fuels that affects fuel moisture calculations, and the wind reduction factor
Climate	Temperature	Influences fuel moisture
	Relative humidity	Influences humidity conditions and propagation rate
	Wind speed and direction	Influences the spread of fire
	Precipitation	Influences humidity conditions and propagation rate

Source: Khalil et al. (2012).

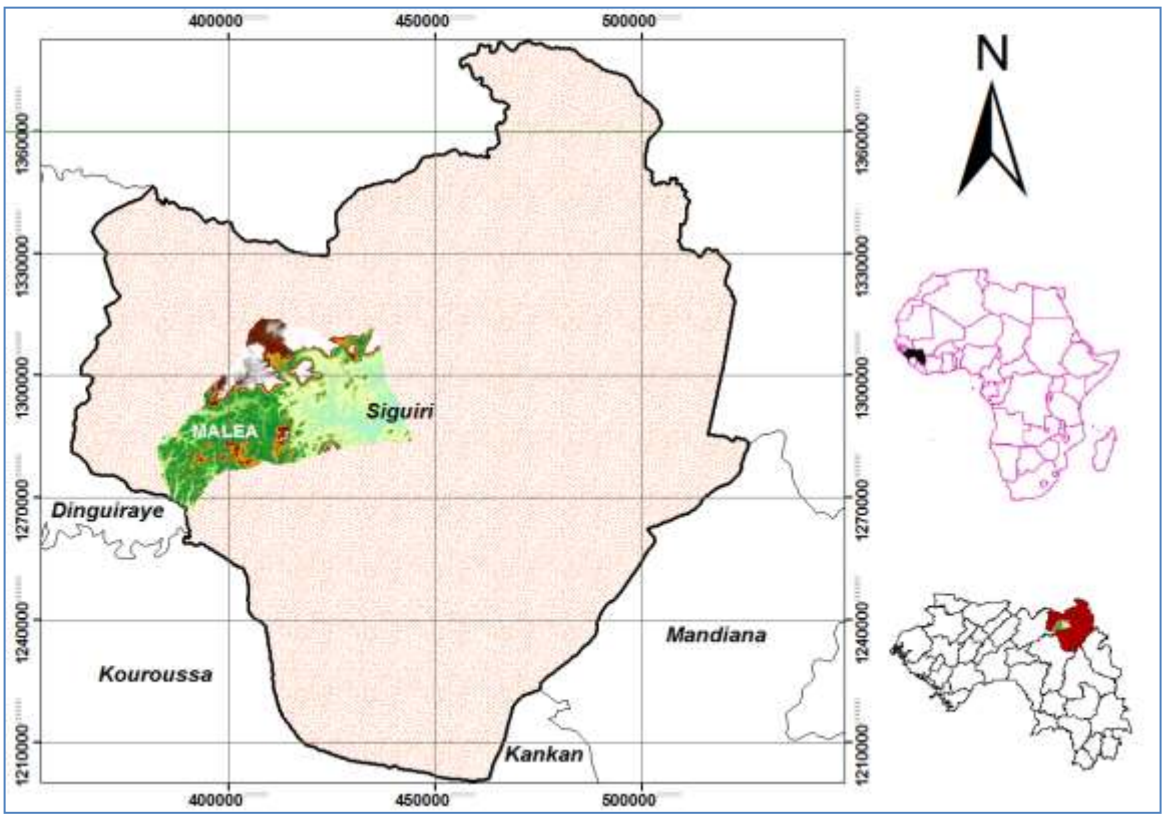

Figure 1. Delimitation of the study area (Malea).

In this study area, the layers of grass are more or less dry during the dry season which runs from November to May; the high occurrence of fires in this zone is observed between December and January.

Methods

We focused our work on a plot of land in the Malea sub-county, Siguiri County, located in Northeast Guinea (Figure 1). The FARSITE Landscape was developed by integrating the fuel model, canopy, elevation, exposure and slope into each FARSITE cell frame. The weather and wind data were adapted before the simulation started. This conceptual diagram (Figure 2) summarizes the different steps leading to the results.

In the conceptual diagram of the FARSITE simulation, vegetation and topography are mandatory parameters; weather gathers the model forcing parameters (Figure 2). For the topography, the 30 m

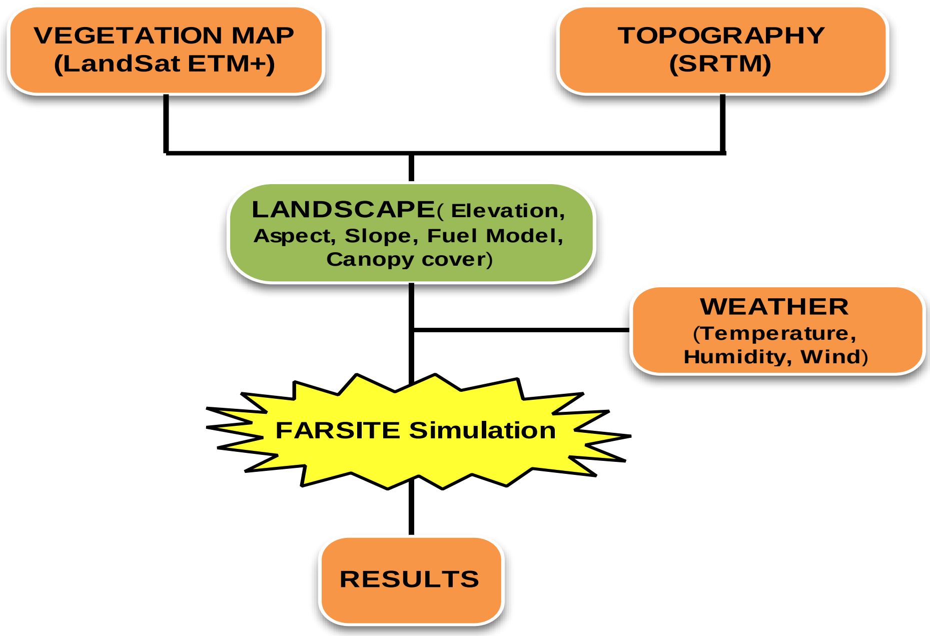

Figure 2. Conceptual diagram of the FARSITE simulation. Vegetation and topography are mandatory parameters, weather gathers the model forcing parameters.

resolution Shuttle Radar Topography Mission (SRTM) was used to produce the elevation maps (For adiabatic temperature and humidity control in FARSITE), slope (for the computation of direct effects on fire spread) and aspect (For determining the angle of incident solar radiation) of the study area using the Spatial analysis tool in ArcGIS 10.0. These relief parameters are constants for a given area (Figure 3). They significantly influence the propagation and their knowledge is essential for any FARSITE simulation. The slope of the terrain produces the same effect as the wind (Ali et al., 2012). In general, as the slope increases, the rate of spread increases, and fires burn more quickly on uneven slopes. The slope exerts a considerable influence on the speed of propagation, especially in the early stages of a fire, so the speed of propagation of a fire will double on a slope of 10% and quadruple by climbing a slope 20%; on the other hand it is considerably reduced when a fire goes down over a slope (Trabaud, 1970).

P < 15%: Low slope with no impact on propagation
15% < P < 30%: Medium slope causing moderate acceleration of the fire front
30% < P < 60%: Strong slope causing a strong acceleration of the fire front
P > 60%: Very steep slope with risk of turbulence, fire jump, general embrace by stains (Ali et al., 2012).

Considering that topography is a static parameter, the main issues are related to the definition of fuel characteristics and the reconstruction of weather conditions. These fuel layers (grass and woody) in this area are supposed to be more or less dry. Predicting fire behaviour by simulation requires detailed knowledge of the fuel as this is the key parameter for any simulation activity with FARSITE (Eva and Fritz, 2003; Lopez Blanco, 2014). Since the characteristics of this fuel cannot be accurately assessed at every point in the study area, it is useful to use a fuel typology and thus categorize it. A landsat ETM+ image with a spatial resolution of 30 m × 30 m covering the area was the subject of a supervised classification which made it possible to categorize the types of vegetation (grasses, shrubs, trees) which are the fuels by referring to existing standards (Keane et al., 2000). The information provided by the Landsat image and thanks to our field knowledge, with reference to Anderson's fuel classification (Anderson, 1982), to highlight six element classes in our study area, namely:
1= short grasses about 30 to 50 cm high;
2= shrubs and undergrowth;
4= shrub field,
9= hardwood litter,
98= water;
-999= no data

A variable declaration with ArcGIS made it possible to establish the useful correspondence taken into account by FARSITE such as:

1=FM1,
2=FM2,
4=FM4,
9=FM9,
98=water ;
-999= missing data.

FM stands for Fuel Model. Fuel model and canopy provide a physical description of the surface fuel bed (Figure 3). In fire ecology, canopy or canopy cover is generally estimated as a percentage and grouped into four categories (Nelson, 1997).

0= no canopy;
1= 1 to 20% canopy;
2= 21 to 50% canopy;
3= 51 to 80% canopy; and
4= 81 to 100% canopy.

The fuel model made it possible to map the canopy based on two considerations:

(i) Not all grassy areas have canopy

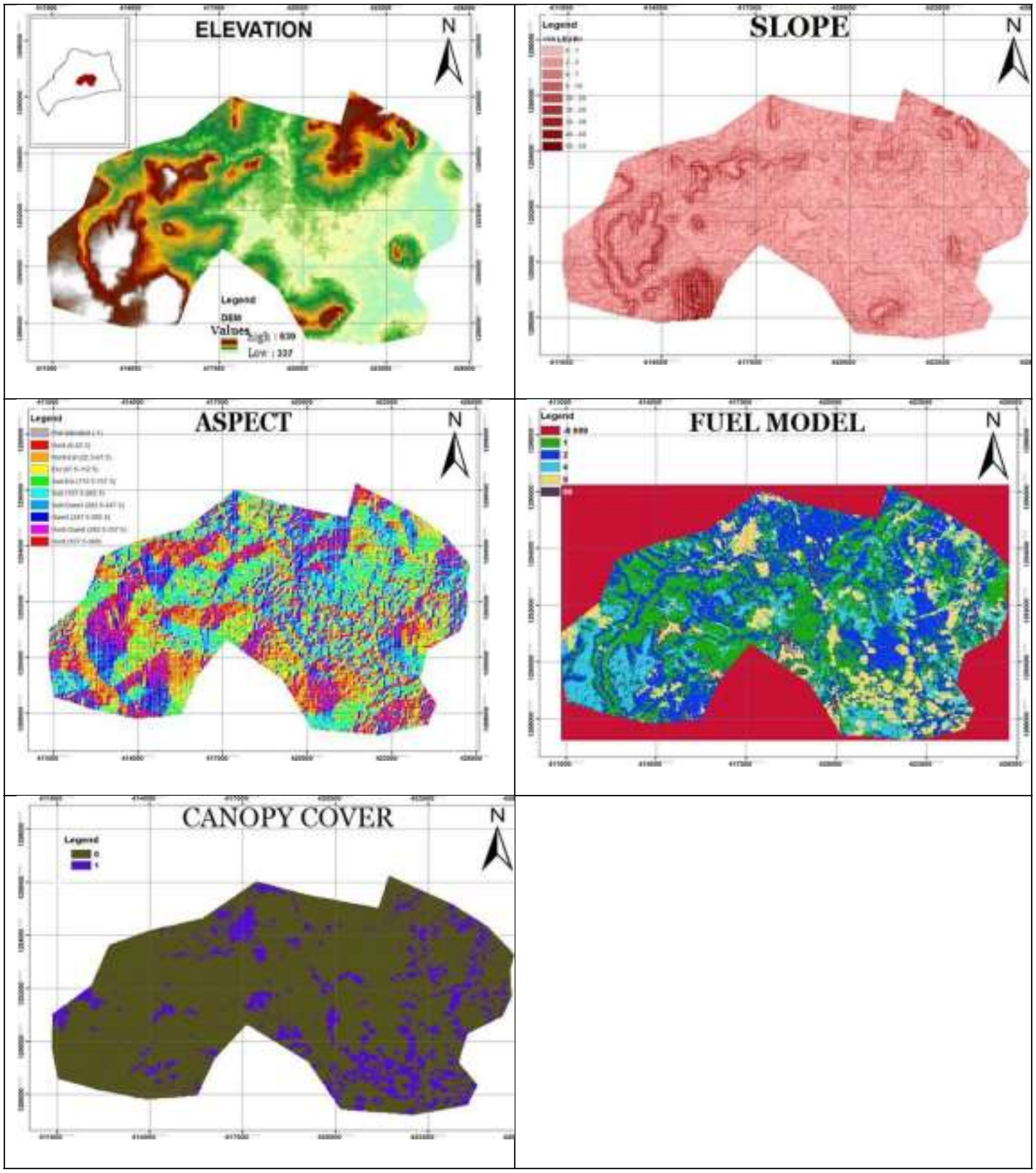

Figure 3. The five important topics input parameters for simulating fire spread in Maléa (Elevation, Aspect and Slope characterize the topography, the fuel model and the canopy cover determine the fuel).

(ii) The shrub and wooded savannah layers have 1 to 20% canopy

The flora cover map or fuel model was then resampled to obtain the canopy (Figure 3) and converted to ASCII format for use in the FARSITE model. Canopy or forest cover. It governs the average shading of surface fuels that affects fuel moisture calculations, and the wind reduction factor.

0=0% no canopy,
1= 1 to 20% canopy.

Winds in the area are very variable and it is an essential factor that provides oxygen, transfers heat by tilting the flame, transports fire over long distances. The wind (Speed and direction per hour), temperature and humidity (Maximum and minimum per day) values included in the model were obtained on the meteoblue site data. These files are readable under the spreadsheet WordPad which was also used for their organization and adjustment. All these files were converted to ASCII (text file) format before being aggregated to FARSITE.

Simulating a fire situation in the FARSITE model requires a point or points of ignition as the starting point of the fire and a duration

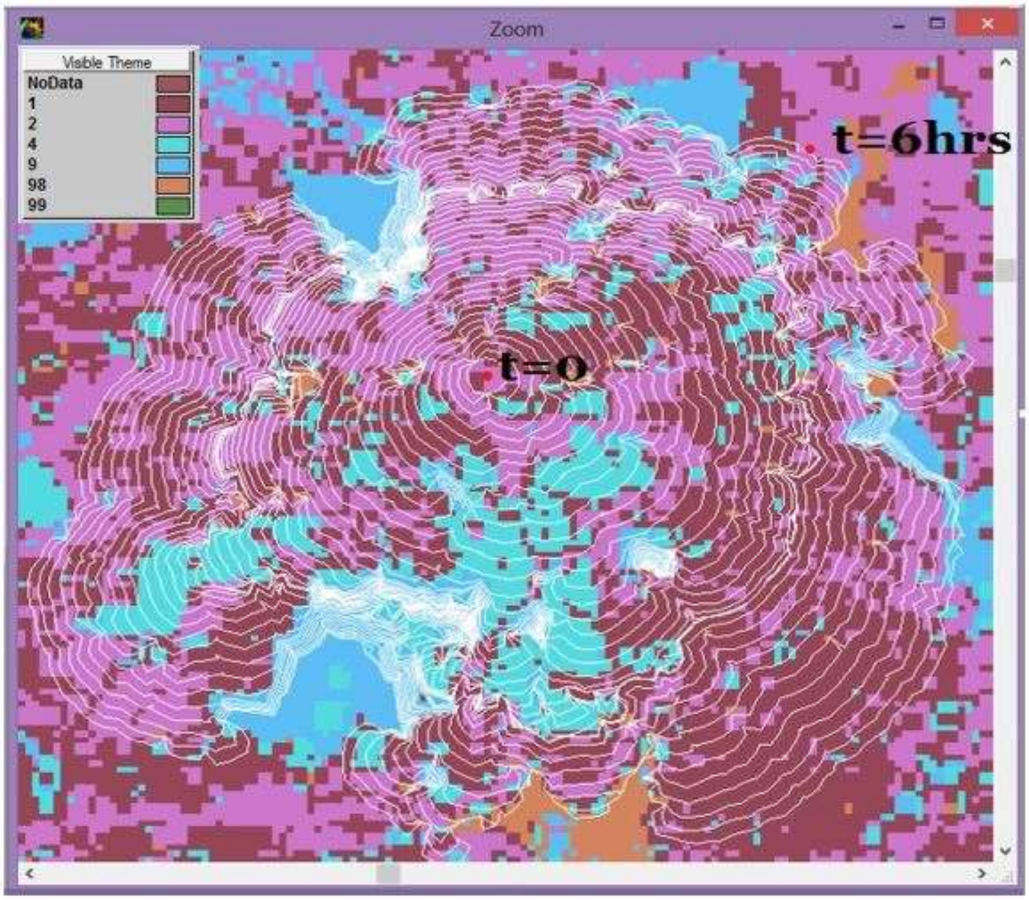

Figure 4. Propagation of windless fires in a plain area. 1 = short grass about 30 cm tall; 2 = shrubs and undergrowth; 4 = shrub field, 9 = hardwood litter, 98 = water; 99 = no data.Curved white lines are fire front lines during spread over different types of fuels.

that is necessary for the start and end of the fire. The ignition points were chosen according to three scenarios:

(i) Ignition and propagation without wind in a space without slope (by canceling wind values in the lowland area)
(ii) Ignition and propagation with wind in a space without slope (lowland area)
(iii) Ignition and wind-free propagation in a slope space (by canceling wind values)

We based our calculations on these three scenarios to clearly show the influence of winds and slopes in fire prediction by maintaining the same time pace. The simulation with FARSITE requires a lot of other calibration processes (see the FARSITE help tool at each step).

RESULTS AND DISCUSSION

Spatial propagation of fires over Malea

Scenario 1: Ignition and windless spread in an environment without slope

Assuming for this first scenario, the absence of the wind by approximation, FARSITE describes exactly what could be observed by experience in the field. The fire would take a quasicircular form and the deformations of the fire front would depend only on the density and the type of fuel and their moisture content (Figure 4). The small intervals between the fire fronts of time t = 0 (firing phase) and t = 6 (hours) end of combustion phase would explain the low rate of propagation in the absence of wind. One can also note the consideration by FARSITE conditions of limitation of the propagation which are among others: the presence of water or fuels too wet to be burned. It is noted in the figure by strong deformations and strong approximations of the fronts of fire.

Scenario 2: Ignition and propagation without wind in a sloping environment

For the second scenario, always keeping the approximation of the absence of the wind, if the environment is almost made up of the same fuel complex, the slopes positively influence the propagation

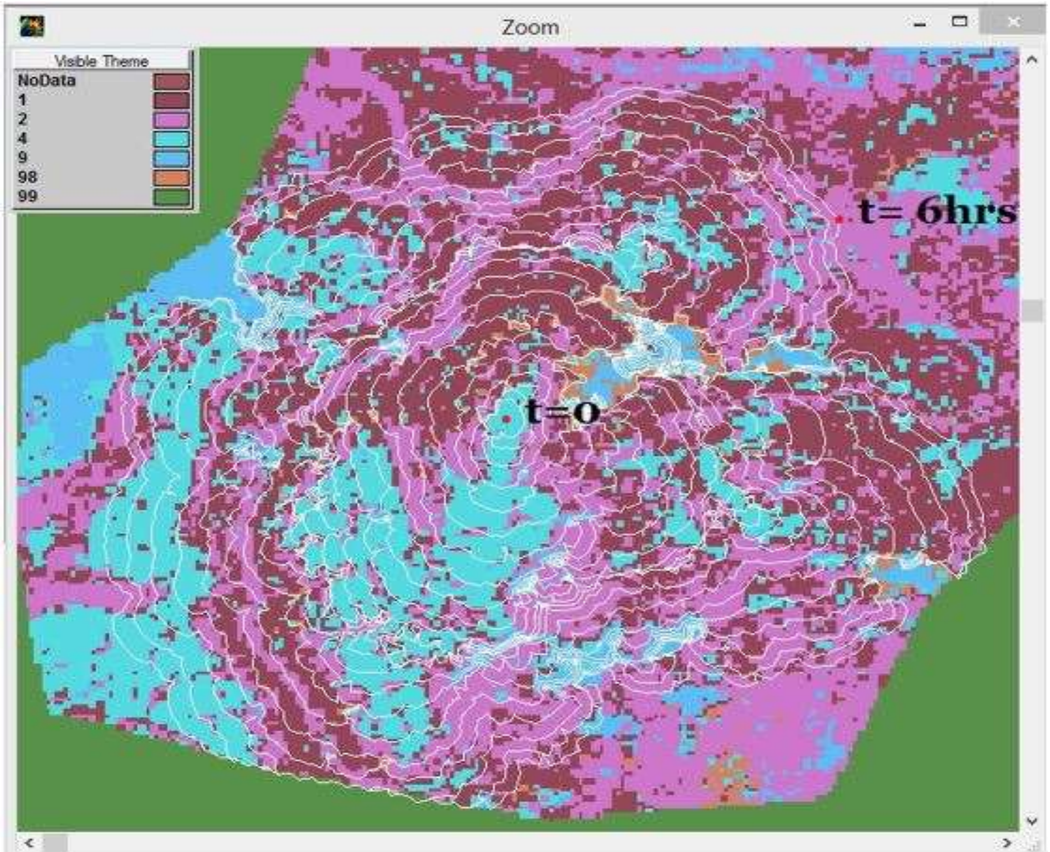

Figure 5. Windless fire spread, in a sloping environment. 1 = short grass about 30 cm tall; 2 = shrubs and undergrowth; 4 = shrub field, 9 = hardwood litter, 98 = water; 99 = no data.The white lines that indicate the fire front lines are more or less oriented.

(Figure 5). Fire rises faster from the slopes and thus increases its rate of propagation, which therefore becomes higher than that of lowland environments. It is also noted that the propagation rate is higher than that of the scenario 1.

Scenario 3: Wind ignition and Fire Spread

The third and last scenario of our observation is that of propagation under the influence of winds (Figure 6). Contrary to scenario 1 and 2, the lines of fire favor a direction that is none other than that of the winds. However, we observe that although the effect of wind minimizes the effects of fuel moisture, the limitations due to water and the area too wet remain observable in the figure, which shows the sensibility of FARSITE. Under the influence of wind, we notice that the effect of wind minimizes the effects of humidity and even those due to the type of fuel. Fire imposes itself and evolves rapidly. In addition to this prediction of spatial spread, we got into the analysis of some other fire behaviours, like time of arrival, spread direction, fire line intensity, reaction intensity, rate of spread and amount of heat released.

Fire behavior analysis over Malea

We processed with GIS software, some outputs of the FARSITE model to predict some fire characteristics during the observed spreading. To facilitate observation, we have grouped the three scenarios at each stage of analysis.

(i)Time: For a duration of 6 h planned during the initialization, we notice that the progression of the fire varies according to the scenario. For the same time intervals, the distances covered in scenario 1 are very identical in all directions. In scenario 2 (slope effect), these distances vary according to the degree of inclination and the other characteristics of the fuel. With the effect of the wind, one can observe for the same time steps, great distances are traveled towards the direction of the wind, and short distances of side opposite the wind (Figure 7). Figure 7 shows that for the same time interval, fire propagation is very quick in the presence of wind and

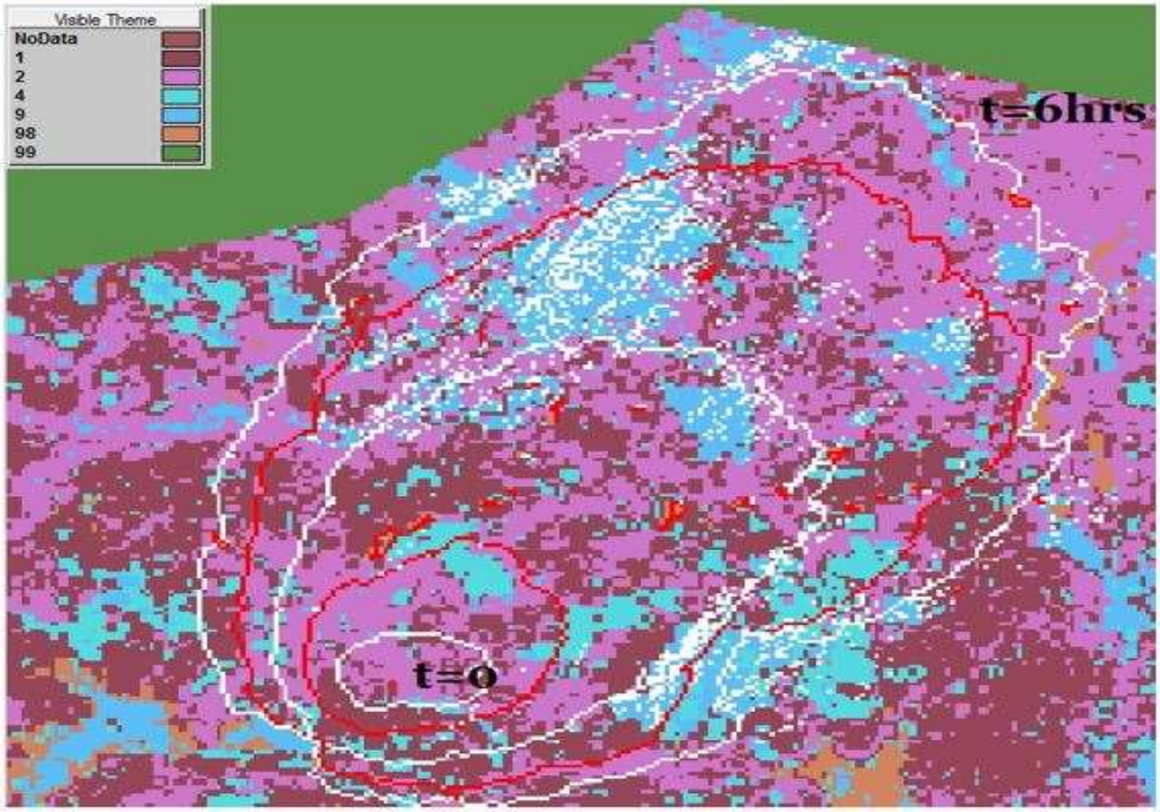

Figure 6. Fire spread with wind, but without slope. 1 = short grass about 30 cm tall; 2 = shrubs and undergrowth; 4 = shrub field, 9 = hardwood litter, 98 = water; 99 = no data. The alternating white and red lines are fire front lines under the influence of the winds.

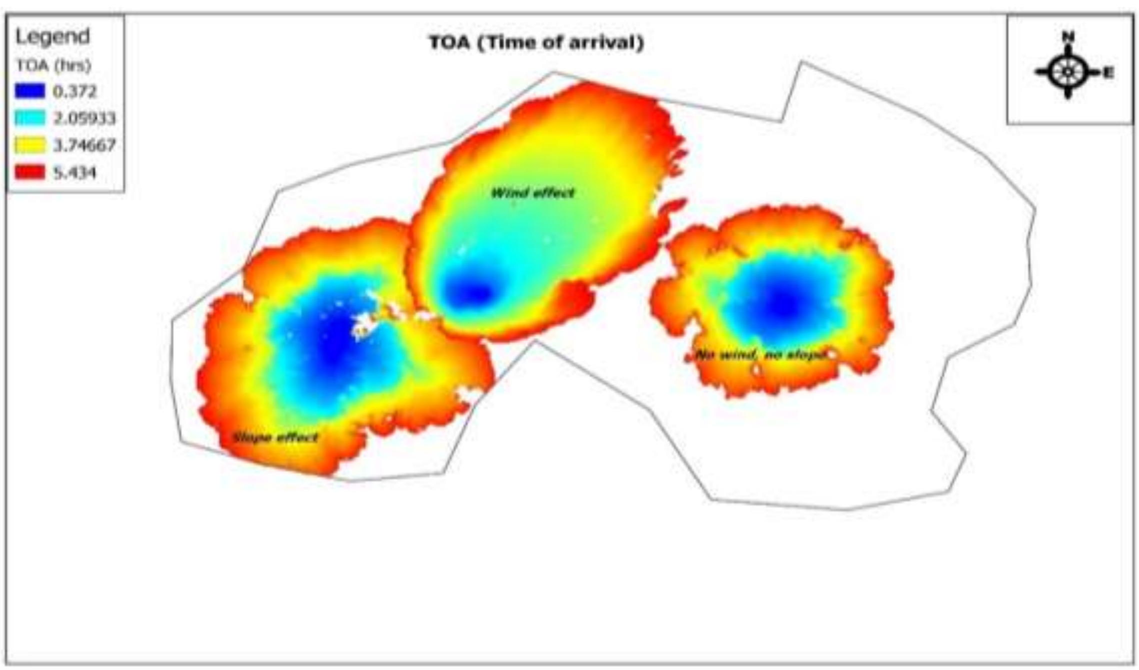

Figure 7. Temporal dynamics of fire. Colour shades typify the time intervals of the fire front in all three cases. The blue part corresponds to the outbreak area or fire start area.

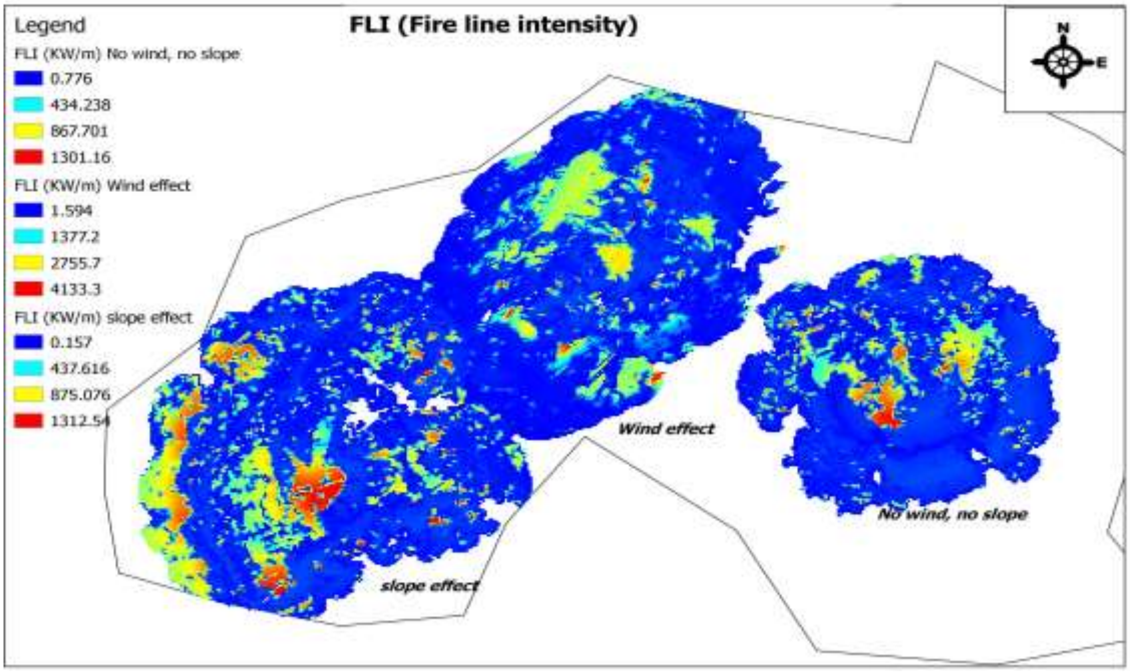

Figure 8. Intensity of fire lines in Kilowatt per meter. The legend shows the intensity variations for each of the three scenarios.

slopes. According to Seigue and Drouet, (1982) and Ali et al. (2012), land slope produces the same effect as the wind. This is true in our case. The fire propagation time projection in our area is a good indicator for foreseeing possible provisions for the safety and properties protection.

(ii) Fire Line Intensity: The intensity of the fire lines depends mainly on the characteristics of the fuel. The type of fuel, its moisture content and its degree of combustion characterize the firepower. The supply of oxygen by the wind is also a key parameter (Figure 8). The intensity of the fire lines can be a function of fuel type, wind and slope, and moisture content. For the same moisture and the same types of flora, the intensity of the fire lines varies according to the speed at which the fire spreads. According to the Canadian Wildland Fire Information System link (http://cwfis.cfs.nrcan.gc.ca/cartes/fb), the calculation of this intensity is based on the rate of spread as well as the total combustion of the fuel. The same source indicates that the intensity of the fire lines can exceed the value of 30 000 KW/m depending on wind speeds and the degree of combustion of the fuel**.**

(iii) The rate of spread: The rate of spread or speed of fire depends on the type of fuel, the degree of humidity, but especially the wind speed and the topography. This speed is at first very low at the beginning of the fire, and it becomes more and more considerable. Figure 9 shows a slight difference between the propagation speeds without wind, no slopes and those without wind, but with slope. One can note that the slopes in our study area are more or less weak as shown in Figures 2 and 3. This is why the propagation rates are close during propagation without wind or slopes and with slopes. Wind, on the other hand, is a major factor in the spread. We observe that the propagation rate takes the values reaching approximately 8 m/min.

Scott and Burgan (2005) categorize rates of spread as follows (Table 2). Without wind, the rate of spread will be low in this area. The presence of winds increases the spread rate which then becomes moderate. This rate can be high when wind speeds increase.

(iv) Reaction intensity: This is the power released by the fire per unit area. This power varies momentarily and its characteristics relate to those of the lines of fire, with the only difference that the latter varies in unit of surface. The intensity of the reaction generally depends on the temporary oxygen supply from the air layers. This contribution is often favoured by the effects of the wind, which explains the very contrasted aspect of the propagation pattern with the effect of the wind (Figure 10). On the other hand, the intensity of the reaction also depends on the type of fuel and the momentum of the fire.

(iii) Heat per unite area: This quantity depends a lot on the degree of combustion. Beyond the emissions of

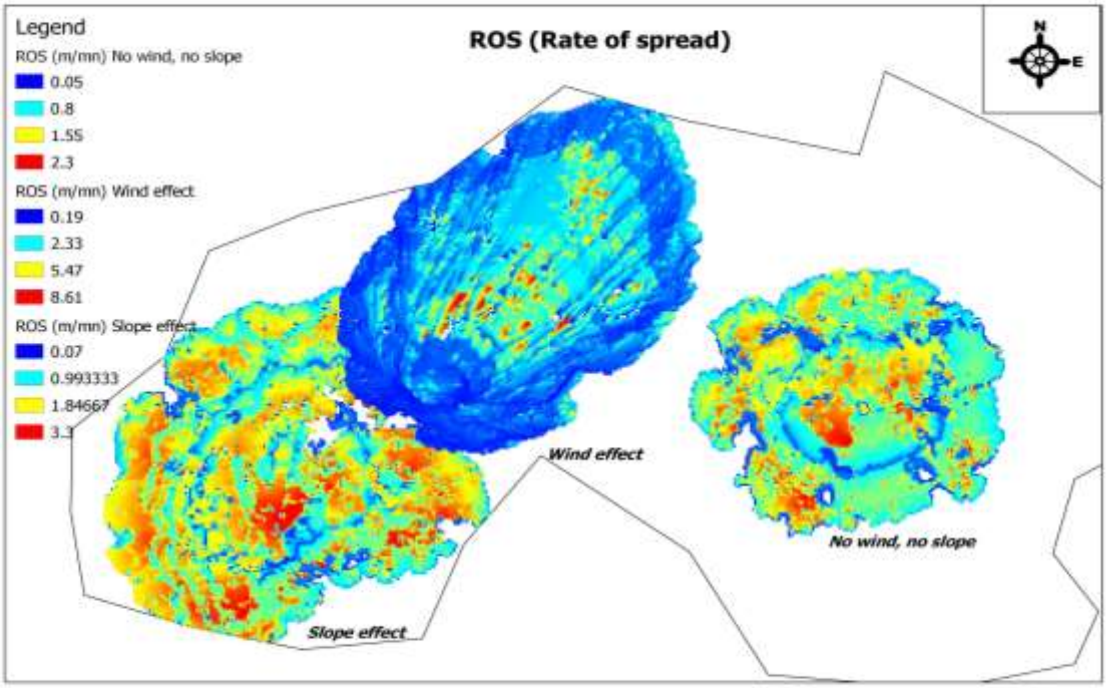

Figure 9. Rate or spread speed for the three (3) scenarios (wind effect, slope effect, without wind or slope).

Table 2. Categorize rates of spread.

0- 2	Very low
2-5	Low
5-20	Moderate
20-50	High
50-150	Very high
150	Extreme

Source: Scott and Burgan (2005).
Rate of Spread (ROS).

particles and gases, fire emits a large quantity of heat which depends on several factors (type and density of fuel, speed of spread, degree of combustion...). Figure 11 predicts the amount of heat emitted per square kilometer for the following scenarios. Wind, through its multiple actions, plays an important role in the outbreak and spread of fires (Trabaud, 1970; Blin, 1974; Stratton, 2009). By its intensity, speed and direction; wind favours and accelerates the drying out of plants and soils; curves and revives flames; brings heat to adjacent fuels; increases the speed of propagation and can produce summit fires that are difficult to control; sometimes transports very far incandescent particles (Trabaud, 1992; Cochrane et al., 2012). For a given fire, the higher the wind speed, the greater the flame spread speed (Trabaud, 1970). It is also interesting to note that the effect of slopes is very similar to that of winds. Fire spreads faster in steeply sloping areas than on plains. Water and bare soil are natural barriers that limit the spread of fire. FARSITE simulation therefore predicts fire behavior with the aim to plan prevention or suppression strategies.

Conclusion

The modeling of spread and behavior fire in the Malea area (Siguiri) prefecture with FARSITE tool (Fire Area Simulator) was possible by crossing satellite data (Landsat, SRTM) with weather data (wind, temperature, humidity). The GIS softwares made it possible to organize this data before integrating it with FARSITE for simulation.

The results obtained show that, in the absence of the

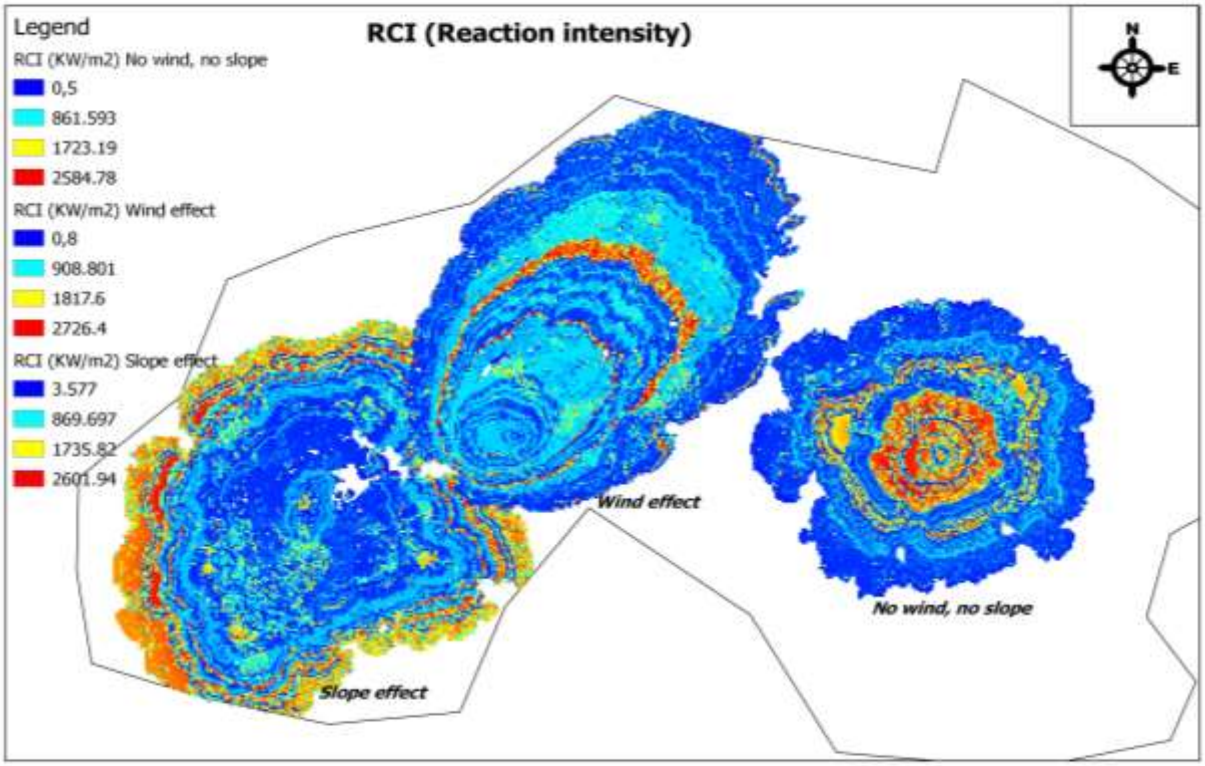

Figure 10. Fire reaction intensity according to the three (3) scenarios (Wind effect, slope effect, windless or slope less).

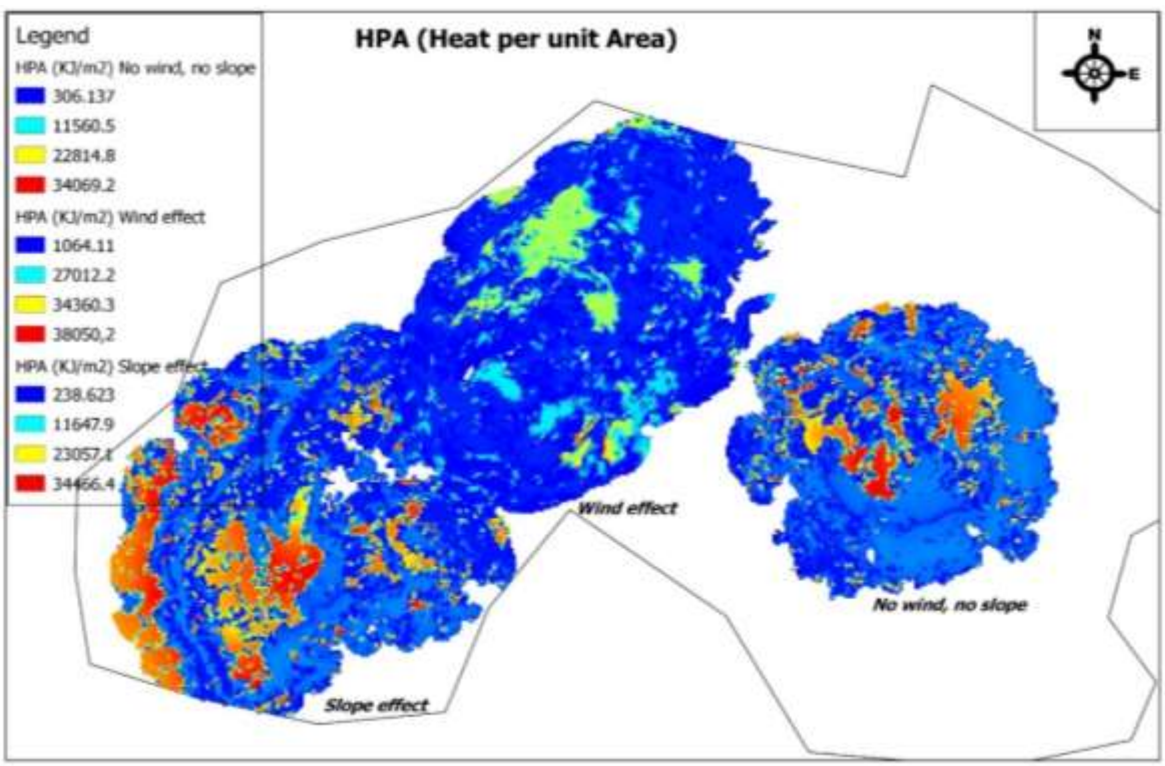

Figure 11. Amount of heat emitted per area (HPA) according to the three (3) scenarios (Wind effect, slope effect, windless or slope less).

wind, the fire would spread more or less uniformly in all directions, the spread of rate would vary between 0.05 and 2.3 m / min and the heat released during combustion would be between 300 to 34000 Kj / m^2, with a power ranging from 0.7 to 1000 KW / m. The presence of slopes would increase the rate of propagation, the power and the heat released by the fire according to the degrees of inclination.

In the presence of winds, the propagation rate could reach the value of 8m / min with a power ranging between 1 and 4000 KW / m. The heat released would be of the order of 38,000 KJ / m^2. For the direction of propagation, the fire in the absence of the wind would have more or less the same probabilities of directional evolution. The wind and the slopes would determine the preferred directions according to their orientation. These results are in harmony with the ordinary observations, which prove the performance of FARSITE (Fire Area Simulator) in the study of fire dynamics and behavior. Although these results are limited by the quality of the data used (weather data in a Siguiri scale), they nonetheless open up a perspective of understanding the fire risks in this area. A detailed study of fuel types and climatic parameters by zone would allow this work to be pursued towards other complex ecosystems of the country in order to limit the damage caused by bush fires.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Comparative assessment of heavy metals in drinking water sources from Enyigba Community in Abakaliki Local Government Area, Ebonyi State, Nigeria

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This study assessed the levels of heavy metals in drinking water sources in Enyigba community in Abakaliki Local Government Area, Nigeria. Four sites were visited for sampling: two surface water (streams) and two underground water (boreholes). Three water samples were collected from each source making it a total of twelve water samples. The levels of Arsenic (As), Cadmium (Cd), Copper (Cu), Zinc (Zn) and Lead (Pb) were determined using an Atomic Absorption Spectrophotometer (AAS). The result showed significantly ($P<0.05$) high level of As, Cd and Pb which also exceeded the World Health Organization (WHO) recommended maximum limits specification for drinking water. The metal index revealed significant ($P<0.05$) elevated level of As, Cd and Pb. There was no significant ($P>0.05$) difference between the stream water and borehole waters in terms of their elemental load. The findings suggest that drinking water from these sources are heavily contaminated by As, Cd and Pb and there is possible risk of contamination of the diverse ecosystem located in the neighbourhood. Therefore, the mining communities and the miners should be properly enlightened on the dangers associated with exposure to heavy metals to prevent them from polluting water bodies.

Key words: Enyigba, borehole, drinking water, stream, heavy metals, pollution.

INTRODUCTION

The inability to access potable water supply in developing countries is a global issue that needs urgent attention. About 884 million people in the world, mostly in developing countries do not have access to drinking water sources that conform to the permissible limit specification of WHO (WHO/UNICEF, 2010). More so, in developing countries of the world, about 780 million people lack access to potable water as result of pollution,

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which has been attributed to contamination with micro-organisms and chemicals. These chemical contaminations involve mainly pollution of water bodies with heavy metals through anthropogenic activities (WHO/UNICEF, 2012).

The principal sources of surface and groundwater pollution by heavy metals are natural processes and anthropogenic activities (Ato et al., 2010; Naveedullah et al., 2014). The rise in concentration of heavy metal in water irrespective of the origin is posing a serious health threats to human and aquatic ecosystems (Humood, 2013; Naveedullah et al., 2014). Arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni) and zinc (Zn) are the most familiar heavy metals of health concern to human (WHO, 2008). When the concentrations of heavy metal in water surpass the environmental acceptable border, the use of such water for agricultural purposes might be detrimental to the aquatic ecosystem and human through the food chain (Wright and Welbourn, 2002). For instance, several kinds of diseases besides organ dysfunction had correlation with raised levels of heavy metal concentrations in drinking water sources above the permissible limit specified by regulatory bodies (Lenntech, 2013).

Additionally, heavy metal contamination of drinking water sources has been linked with deficiencies of some essential nutrients, which culminates in compromised immunological defenses, disabilities associated with malnutrition, intrauterine growth retardation, impaired psychosocial faculties, and increased prevalence of upper gastrointestinal cancers (Arora et al., 2008). Although few of these heavy metals like Cu, Iron (Fe), Ni and Zn are essential nutrients required in trace amount for animals and plants; they are harmful at high levels. However, some heavy metals like Cd, Cr, Pb and cobalt (Co) have no known physiological functions and are deleterious at certain levels (Aktar et al., 2010; Kar et al., 2008).

Despite the substantial contribution of small-scale mining to the economy of Ebonyi State and Nigeria at large since the discovery of Pb-Zn deposit in Enyigba and its environs in the early 1900s, it has impacted negatively on the environment and health of the residents (Nnabo, 2015). This study is therefore aimed at determining and comparing the levels of some heavy metals (Pb, Cd, As, Cu and Zn) in the drinking water sources from Enyigba mining community in Abakaliki Local Government Area. It also seeks to assess the trace metal indices in comparison with the observed concentration of water quality permissible limit specified by WHO (2011).

MATERIALS AND METHODS

Study area

The study was carried out in Enyigba, a mining community, located in Abakaliki Local Government Area of Ebonyi State, South Eastern region of Nigeria. Enyigba shares borders with Ikwo Local Government Area, precisely at Amechara, Ameri and Amegu communities. It lies between latitude $6°27^{1}5.0^{11}$ north of the equator and longitude $8°26^{1}11.0^{11}$ west of the Greenwich meridian as recorded by a conventional global positioning system (Google map-GPS). The topography of Enyigba is undulating plain alternating with running of ridges and hills from east to west. The plains are underlain by shale outcrops, which serve as the host for Pb-Zn mineral ore bodies. The area had about 60 m as its highest elevation and 30 m as its lowest elevation above sea level. The area falls within the tropical rainforest belt of South East, Nigeria and characterized by an average rainfall of 1750 to 2000 mm per annum. The highlands are characterized by drought resistance grasses, along stream and rivers. The area is majorly drained by Ebonyi River. All the drainage systems flow eastward to join the cross river somewhere outside the area (Nnabo, 2015) (Figure 1).

Water sample collection

Water sampling was carried out in the month of May. Water samples for analysis were collected from surface waters (streams) and underground sources (Borehole water). These sources are representative of the drinking water sources of the inhabitants of the community. Four sites were visited for sampling; two surface sources: Nwangele Orugwu streams (stream 1) and Inyina stream (stream 2) and two underground sources: Enyigba Primary School borehole (borehole1) and Ishiagu Enyigba town hall (borehole 2). In each site, three water samples were collected, making it a total of twelve water samples.

Digestion of water samples for analysis of As, Pb, Zn, Cu and Cd

Turbid water samples from the streams were digested before the proper analysis using the method as described by American Public Health Association (APHA, 1998).

Procedure

The water samples were thoroughly mixed by shaking. Three different water samples from each of the surface water sources (Nwagele Orugwu stream and Inyina stream) were digested as follows: 50 ml of the sample was transferred into a glass beaker and 1.0 ml of concentrated nitric acid was added. The beaker with the contents was placed on a hot plate and evaporated down to about 20 ml. On cooling, the sample was filtered through Whatman No. filter paper 42 to remove some insoluble materials that could clog the atomizer. The volume was adjusted to 50 ml using metal free distilled water.

Quality assurance and quality control

Strict quality assurance and quality control procedures were employed in order to ensure authenticity, correctness and precision of the results. All the reagents and chemicals used were purchased from Sigma-Aldrich (Sigma-Aldrich Co. LLC, USA) and were of analytical grade.

Glass wares used during laboratory analysis were thoroughly washed with several changes of 9% HNO_3 and properly rinsed several times using de-ionized water. Dilutions were carried out using de-ionized water.

A blank solution and standards were analyzed along with the replicate samples to ensure precision and accuracy of the determinations.

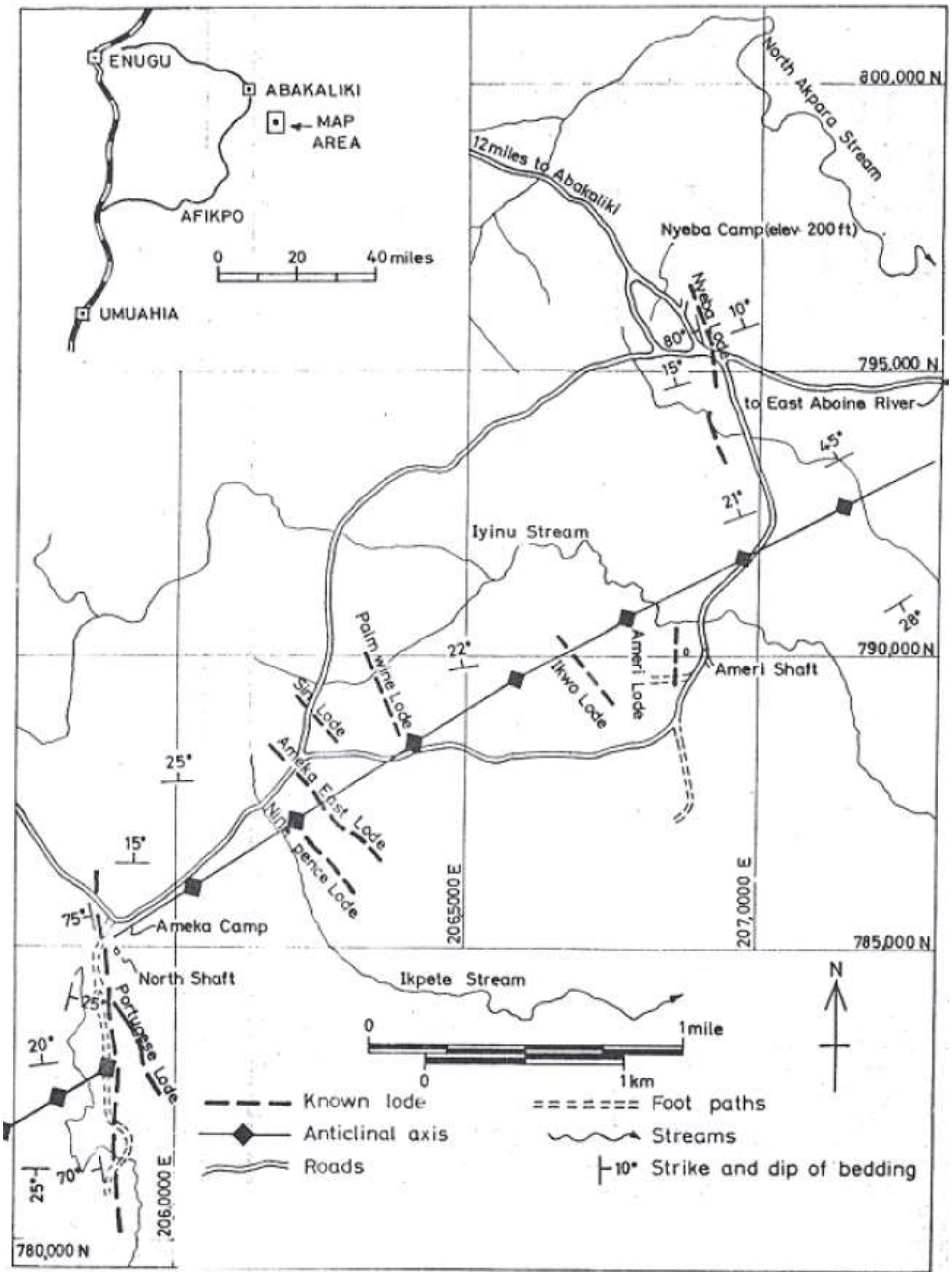

Figure 1. Geographical map of lead-zinc deposits of Enyigba district, near Abakaliki, lower Benue Trough. The area is underlain by Abakaliki shales.
Source: Modified by Orajaka (1965).

Metal index (MI)

MI was calculated using the method described by Akpoveta et al. (2011) as follows:

$$MI = Mc / MAC \quad (1)$$

where Mc represents the concentration of metal in the test sample, MAC is the maximum allowable concentration of metal in drinking water as specified by WHO (2011). Values < 1 indicates significant degree of contamination and values >1 shows no contamination. Metal indices provide information on the relative contamination contributed by individual metal in a water sample.

Statistical analysis

Results were expressed as mean ± standard deviation of three replicates. Data obtained were analyzed using SPSS (version 15 Inc., USA). The values of $P<0.05$ were considered statistically significant.

RESULTS

The result in Table 1 showed that the mean arsenic (As) and lead (Pb) concentrations in water samples from both streams and boreholes exceeded the WHO (2011) permissible maximum limit of 0.010 mg/L for drinking water. The results of the mean concentrations of Cd from water samples collected from stream 2 and borehole 2 were within the WHO (2011) permissible limit while the level recorded from stream 1 and borehole 1 was above the WHO (2011) permissible maximum limit of 0.003 mg/L for drinking water. The results of the mean concentration levels of Cu and Zn in water samples from both streams and boreholes were within the WHO (2011) permissible limit of 2.0 mg/L for drinking water.

The result in Table 2 revealed significantly ($P>0.05$) high metal indices for As, Cd and Pb in both streams and boreholes which were above the WHO permissible limit while the metal indices for Cu and Zn were within WHO permissible limit.

DISCUSSION

The present study observed significantly higher concentrations of As and Pb in both streams and boreholes when compared with the WHO permissible limits for drinking water, with high metal indices for the two metals. However, while level of Cd was within the WHO permissible limit in Inyina stream and Ishiagu Enyigba town hall borehole, the level of the metals was above the WHO permissible limit for Nwangele Orugwu stream and Enyigba Primary School borehole. Meanwhile, levels of Zn and Cu observed in both streams and boreholes were within the WHO permissible limits with low metal indices.

The significantly elevated As concentrations in both streams and boreholes which exceeded the WHO (2011) permissible maximum limit of 0.010 mg/L for drinking water in the current study in agreement with previous findings (Nnabo, 2015). The significantly raised metal index for As was an indication of high contamination. The high concentration of As may be as a result of mining activities or runoff from agricultural areas, where material containing As such as fertilizer and pesticides was used (Cobbina et al., 2015). It has been reported that mined rocks and ore containing arsenic piled up in proximity to surface water bodies may be leached into drinking water sources (Ravengai et al., 2005). The implication of this finding is that the residents may be at risk of As poisoning through consumption of such polluted water. The effect of As on human health is well known. For instance, elevated level of As in blood/plasma (e.g. through consumption of water and food) is associated with pigmentation changes, skin lesions and hard patches on the palms and soles of the feet (hyperkeratosis), which serves as precursors for skin cancer. Besides skin cancer, As exposure also causes cancer of the bladder and lungs. Hence, the International Agency for Research on Cancer (IARC) has classified As and its compounds as carcinogenic to humans, and has also stated that As in drinking-water is carcinogenic to humans (Flanagan et al., 2012).

The results of the mean concentrations of Cd from water samples collected from Inyina stream and Ishiagu Enyigba town hall borehole were within the WHO (2011) permissible limit while the level recorded from Nwangele Orugwu stream and Enyigba Primary School borehole were above the WHO (2011) permissible maximum limit of 0.003 mg/L for drinking water. The metal index for Cd was high which indicates significant contamination. The present findings are in consonance with the result of previous study conducted in the area which reported that concentration of Cd from Enyigba stream was 6 and 0.5 mg/L in Enyigba Primary School borehole which were above the stipulated limit by regulatory bodies (Nnabo, 2015). The high concentration of Cd in water sources in the area could possibly be due to their waste disposal method, natural processes, anthropogenic activities, human activities and their agricultural methods (WHO, 1998a, b; Patrick et al., 2002; Ejikeme, 2003). Yakasai et al. (2004) revealed that the concentration of Cd and other heavy metals in ground water is dependent on the closeness of the water source to the roads with high traffic density, industrial activities like metal melting and coal refining and oil fired power stations, electroplating plants, rate of development of the area, the topography of the land, climatic conditions and solid waste disposals. Environmental exposure to Cd has detrimental health hazard as it is toxic and has cumulative effect (Ferrer et al., 2000; Klaassen, 2001). Kidney being the major storage organ for Cd is the critical organ that first display signs of toxicity (Nordberg, 2001).

The significantly ($p<0.05$) high concentration of Pb obtained in this study which exceeded the WHO permissible limit is in tandem with the previous study conducted in the area which reported that concentration of Pb from Enyigba stream was 0.7 and 0.1 mg/L in Enyigba Primary School which were above the stipulated limit by regulatory bodies (Nnabo, 2015). The high metal index for Pb observed in the present study shows significant Pb contamination of water sources. Pb as a result of its insoluble nature, decreased rapidly with distances away from the mineralization zones (Bolucek, 2007). High concentration of Pb in streams could be due to disintegration/breakdown and leaching of lead from waste rocks dumps (Cobbina et al., 2015). This has important public health implications as Pb poison can affect both the foetus and neonates because it excretes through the placenta and breast milk. Miscarriage, still birth, and premature birth are among the complications reported in mothers due to Pb poisoning. Developing brains (fetal, neonatal and infant brains) are highly prone

Table 1. Mean concentration of heavy metals in drinking water sources in Enyigba.

Heavy metal (mg/L)	Stream 1	Stream 2	Borehole 1	Borehole 2	WHO (2011)
As	0.091±0.055[a]	0.187±0.047[a]	0.075±0.041[a]	0.485±0.510[a]	0.010
Cd	0.094±0.124[b]	0.002±0.0204[b]	0.012±0.021[b]	0.003±0.005[b]	0.003
Cu	0.075±0.046[c]	0.067±0.057[c]	0.009±0.008[c]	0.023±0.025[c]	2.000
Zn	2.015±2.011[d]	1.555±0.457[d]	0.078±0.073[d]	0.175±0.133[d]	3.000
Pb	0.574±0.345[e]	0.272±0.157[e]	0.077±0.133[e]	0.043±0.075[e]	0.010

Values are mean ± standard deviation of three values. The values with the same superscript along the row were not significantly different (P>0.05).

Table 2. Metal Index of the heavy metals in the drinking water sources.

Heavy metal	Stream 1	Stream 2	Borehole 1	Borehole 2	Standard (WHO, 2011)
As	9.10±5.50	18.70±4.70	7.50±4.10	48.50±51.00	0.01
Cd	31.30±41.30	0.67±6.70	4.00±7.00	1.00±1.70	0.003
Pb	57.40±34.50	27.20±15.70	7.70±13.30	4.30±7.50	0.01
Cu	0.04±0.02	0.03±0.03	0.01±0.01	0.01±0.01	2.00
Zn	0.70±0.67	0.52±0.15	0.03±0.02	0.06±0.04	3.00

The values show mean ± standard deviation of three replicates of water sample. Values > 1.0 indicates significant contamination while values < 1.0 indicates no contamination (Akpoveta et al., 2011).

to Pb poisoning (Vasudevan et al., 2011).

The result of the mean concentration levels of Zinc in water samples from both streams and bore-hole were within the WHO (2011) permissible limit of 3.0 mg/L for drinking water. The value of the metal indices is low which shows no contamination by Zn. The previous study conducted in the area reported that concentration of Zn from Enyigba stream was 10.1 and 6.6 mg/L in Enyigba Primary School which were above the stipulated limit by regulatory bodies (Nnabo, 2015) and this is at variance with the current study. An elevated dose of Zn over an extended period of time is accompanied with Cu deficiency. There is a competitive absorption between Cu and Zn within the enterocytes. The clinical manifestation of Cu deficiency includes hypocupremia, impaired iron mobilization, anemia, leucopenia, neutropenia, decreased superoxide dismutase, ceruloplasmin as well as cytochrome-c oxidase, but elevated plasma cholesterol and abnormal cardiac failure (Laura et al., 2010).

The results of the mean concentration levels of Cu in water samples from both streams and bore-holes were within the WHO (2011) permissible limit of 2.0 mg/L for drinking water. The value of the metal indices for copper is low which indicates no contamination. The present study is in agreement with the previous study conducted in the area which reported that concentration of Cu from Enyigba stream was 0.08 mg/l which was within the stipulated limit by regulatory bodies (Nnabo, 2015). Cu toxicity induces Zn deficiency that can result to anxiety state through over-production of catecholamines (epinephrine, norepinephrine, dopamine and serotonin) (Eck and Wilson, 1989).

Moreso, The present findings from different streams and boreholes indicate that irrespective of the water source, be it stream or borehole, the levels of As and Pb were elevated. This shows that this area is highly polluted by these metals. Consequently, proper monitoring of these water sources is required. Hence, water from these sources need to be treated to remove these heavy metals probably by using available remediation technologies such as ion exchange, bioremediation, membrane filtration, heterogeneous photocatalyst, etc.

Conclusion

The study showed that drinking water from these sources is heavily contaminated with As, Cd, and Pb which exceeded the WHO recommended maximum limits specifications for drinking water. There is urgent need for proper regulation of mining activities and monitoring of heavy metal levels in drinking water sources. The mining communities and the miners should also be enlightened on the possible health risk associated with exposure to heavy metals to prevent them from polluting water bodies. Besides, drinking water from these sources should be properly treated before consumption to remove these heavy metals.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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A critical look at the Ghanaian one district one factory industrial policy in relation to climate change

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This paper takes a critical look at Ghana's one district one factory industrial policy in relation to climate change. This is important because climate variability and change as a result of industrialization can stand as hazard to impending advancement and expansion in Ghana. Industrial policy can contribute significantly to economic, ecological as well as communal sustainability. This paper aim to clarify the need for industrial policy because of climate change as well as to determine its effects on the one-district, one-factory industrial policy in Ghana. A far-reaching work examination was done on detailed comparative account of the role played by industrial Policies due to climate change in development and growth. This search resulted in the selection of four implications namely: international coordination, green industrial policy, energy efficiency and diversifications; and trade policies, which were missing in the 1D1F industrial policy in Ghana.

Key words: Climate change, energy; industrial policy, trade policy, sustainable development.

INTRODUCTION

Ghana is one of Africa's fastest growing economies, which has taken noteworthy progresses in poverty decrease, but climate unpredictability as well as change stand as hazard to impending advancement and expansion. Ghana has attained a reduced middle-income status and seeks to attain a full-grown middle-income nation in the future. Although the government to set the country's resources to judicious usage as they sustain the economic development, implements responsibilities as well as the country and its people growth, one challenge of environment-development relationship that is the growing threats of global warming, of which Ghana is not exempted. Climate change in Ghana can develop into a grave hazard to livings and there is minute or no strong indication of devoted reaction to climate change (Amuakwa-Mensah, 2014; World Bank, 2009). Instead, most government's frontrunners choose to approve political contracts and memo rather than exercising suitable techniques of alleviating the danger of climate change. In recent times, Ghanaians boost of the governments' quest to implement the industrial policy (IP) of one district one factory (1D1F) in its 254 districts. The specific aim of the 1D1F is:

(1) To create massive employment particularly for the youth in rural and peri-urban communities, thereby improve incomes levels and standard of living, as well as reduce rural-urban migration.

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(2) To add value to the natural resources of each district and exploit the economic potential of each district based on its comparative advantage.
(3) To ensure even and spatial spread of industries and thereby stimulate economic activity and growth in different parts of the country.
(4) To promote exports and increase foreign exchange earnings to support the government's development agenda.

This 1D1F industrial policy is an excellent industrialization initiative and requires a critical look in relation to climate change. Before the methods, results and discussions the fundamentals of climate change finances as it relates to industrial development and procedure is reviewed to offer a satisfactory structure of situation and pressure the formidable difficulties on the track of industrialization.

Even though industrial development leads to wealth creation and social transformation, it can also affect the environment and contributes ultimately to climate change if not done sustainably. A country's IP is actually directs an administrative interference in the economy (Evenett, 2006). Government takes measures aimed at improving the competitiveness and capabilities of domestic firms and promoting structural transformation. A country's industrialization often has a key role in IP and it is very important to implement IP (Rodrik, 2007).

In recent times most countries have been implementing IP (Perez and Primi, 2009). Naudé (2010a and b) argues that there exists numerous justifications for IP, comprising the dangers as well as prospects posed by climate change. This paper aim to make clear the necessity for IP owing to climate change as well as to define its inferences in Ghana pertaining to 1D1F policy. An important point of leaving is that IP is important for environmental and societal tolerability. In a world characterized by growing inequity, industrial development proposes opportunities for employment creation, revenues and the opportunity for industrially holdup nations to catch up. Altenburg (2009) describes climate change as one of the most important challenges facing IP. According to Naudé (2011) and Naudé and Alcorta (2010), achieving low-carbon industrialization is going to require selective government intervention and neutrality towards all products and processes. The necessity to make accurate decisions will be more superficial as the world's populace rises to above 9 billion persons by 2050 (Naudé and Alcorta, 2010). A rising populace with amassed procuring influence will request novel and additional merchandises as well as methods to make them that would not just have a weighty clang on the environs but would also put weighty force on the obtainability of natural resources to make them (Naudé, 2011). Furthermore, indorsing low-carbon industrial development as well as procurement of its supplementary growth remunerations will itself advance the capability of current underprivileged nations to acclimate to climate change (Szirmai, 2012).

Although the Earth's climate(s) has continuously been fluctuating, there is currently an extensive understanding that the climate is warming and anthropological release of Greenhouse Gases (GHGs) which is an anthropogenic global warming is a causative influence. According to Tol (2010), every household, company, farm, releases some greenhouse gases. One such weighty level emanates from industrialized activities. According to IEA (2009), industry demand institutes about 30% universal ultimate energy request and is accountable for about 40% of all energy-related releases, with pulp and paper, iron and steel, chemicals and petrochemicals, cement, and aluminum making as the utmost carbon intensive. The human released element of GHGs in the air has increased significantly from the time of the earliest Industrial Revolution. It stands as threat for humanoid wellbeing as climate warming is comes with countless adverse effects on society.

Climate change is foretold to have specific economic and communal influences over numerous passages; furthermore, these are predictable to be different geographically and emerging nations are projected to be the vilest affected. These influences and concerns will entail adaptation to climate change along with activities to alleviate global warming. Industrialization has always seemed to be the key to wealth creation but in reality, it has been shown that, although it leads to better conditions of living in certain respects, it affects the environment and ultimately, contributes to climate change (Mgbemene et al., 2016). Industrialization not only involves technological innovations, it also involves economic and social transformation of the human society.

Industrialization comes with opportunities as well as challenges. The challenges include pollution, changing human life styles and changing philosophies. Due to these challenges, industrialization must take into account climate change and its consequences according to Equation 1.

$$\text{GHG emissions} = \text{population} \times \{(\text{GDP}/\text{Population}) \times (\text{Energy Use}/\text{GDP}) \times (\text{GHG emissions}/\text{Energy Use})\} \quad (1)$$

According to The Kaya identity as shown in Equation 1, the first expression on the right side specifies the connection with profitable development and the second and third expressions indicates the connection with invention. Industrial development consequently donates to GHG releases through (i) encouraging general GDP development; (ii) having a vivid general influence on energy demand and usage; and (iii) using carbon-intense invention techniques.

According to Ojha (2008), global warming will be harmful to economic expansion and subscribe to higher poverty. Climate change will have such a serious impact on economic growth that 1% of global gross domestic product (GDP) will be required to mitigate its effects (World Bank, 2009). Many studies have presumed a rise

Table 1. Global estimates of the cost of inaction due to climate change.

Study	Warming (°C)	Impact of % GDP	Regional disaggregation	Sectorial/thematic disaggregation
Nordhaus (1994a)	3.0	-4.8		
Nordhaus (1994b)	2.5-3.0	-1.3		
Frankhauser (1995)	2.5	-1.4	✓	✓
Tol (1995)	2.5	-1.9		
Nordhous and Yang (2007)	2.5	-1.7	✓	
Nordhous and Boyer (2000)	2.5	-1.5	✓	✓
Tol (2002)	1.0	2.3	✓	✓
Maddison (2003)	2.5	-0.1	✓	
Rehdauz and Maddison (2005)	1.0	-0.4	✓	
Nordhaus and Yang (1996)	2.5	-0.9	✓	
Stern (2007)	2.3	-3.0		

Source: Adapted from Tol (2011).

in universal mean temperature of either 1 or 2.5°C, which is presumed to ensue if the volume of GHGs in the air is doubled. According to Stern (2007) and Tol (2011) climate change's economic harms will make about 12% of global GDP, and that the prices of extenuation leading to a low-carbon economy will be much lesser, around 1% of global GDP as shown in Table 1. The only choices accessible to us are to acclimatize by being cognizant of this singularity or discovering methods of extenuating its influences (Amuakwa-Mensah, 2014; Atazona, 2013). The impact of climate change is likely to be severe but the costs of avoiding this relatively small, if the world acts without delay (Stern, 2007; Tol, 2011). Therefore Long-run economic development in Ghana as the government intends makes Ghana potentially vulnerable to anthropogenic climate change. This would be detrimental to the country given the country's dependence on rainfed agriculture, hydropower, and unpaved rural roads. As anticipated/forecasted by the World Bank (2009), global climate change will have an excessively negative effect on emerging nations, especially on agricultural efficiency in South Asia, Africa and parts of Latin America.

MATERIALS AND METHODS

Industrialization has become a development priority for a number of developing countries. These countries are elaborating ambitious and long-term industrial development plans that provide a clear vision and rationale for industrial development and promote skills and resources to meet the industrial development challenge. This industrial development challenge has a potential to affect the environment and ultimately contribute to climate change. There is therefore the need to clarify the need for IP due to climate change in Ghana. Most of the existing literature and data relating to industrial policy due to climate change in Ghana were scanty. The National Climate Change Policy as an assimilated reaction to weather alteration in Ghana is a great idea. Even if it offers an obviously clear passageway to deal with issues of climate change in the socio-economic situation of Ghana, it appears not to have no secure grounds in terms of sustainability operation (MOTI, 2010). To fully understand industrial policy due to climate change globally an extensive literature search was carried out on detailed comparative account of the role played by industrial policies due to climate change in development and growth in different countries, their different effectiveness, the importance of varying combinations of polices measures and the details of their implementations as shown in Table 2. The following four implications were selected because those were missing in the United Nation documents on industrial policy process in Ghana, namely the international coordination, green industrial policy, energy efficiency and diversifications, and trade policies. The aim is to clarify the need for IP because of climate change as well as to regulate its inferences for the one district one-factory industrial policy in Ghana. Four insinuations are deliberated, specifically the need for Universal management, green industrial policy, energy efficiency and diversifications, and trade policies.

RESULTS

International coordination

Dealing with climate change is an economic necessity. According to IPCC (2007), climate change impacts are very likely to increase due to increased frequencies and intensities of extreme weather events and that aggregated and discounted to the present, they are very likely to impose costs, and these costs will increase over time. However, a coordinated international response can drive down the cost of mitigation compared to each country doing this in isolation at home.

Developing countries have been predicted to experience the greatest impacts from climate change. This is because many of the developing countries are vulnerable and regrettably poor in terms of development to mitigate the challenge of climate change. For the countries most vulnerable to climate change, the most reliable defense lies in economic development itself. The advanced industrial countries that have been primarily responsible for bringing about climate change will most

Table 2. Overview of global industrial policy due to climate change.

References	Climate change worst off region	Industrial policy application
Naude (2011)	Developing countries	Yes
Hope (2006)	Asia	Yes
Maddision (2003)	South America	Yes
Meadelsoln et al. (2000)	Africa	No
Plambeck and Hope (1996)	Asia	Yes
Tol (1995)	Africa	No
Frankhauser (1995)	China	Yes

likely not experience its most severe impacts. They have a responsibility to assist both poor and genuinely developing countries to find a path of development that does not exacerbate global harm. In the past IP was very much nationally oriented with little collaboration and management between countries. This increases subjects of the suitable and actual official devices to attain such management. In Africa, the case for international coordination of IPs needs to be considered and the biggest platform to ensure and monitor compliance is Africa Union AU.

Currently, from the earliest industrial revolution, many emerging nations are not key GHG emitters, even big developing markets like China, India and Brazil release comparatively slight in apiece terms though because of the proportions of their populaces as well as economies their entire releases are important (Ojha, 2008). Conversely, to the extent that the future is apprehensive, the IEA (2009) assumes that the entire predictable upsurge in CO_2 releases from now to 2030 will come from emerging nations mostly India, the Middle East and China. About 75% of the projected 12 Gt upsurge in yearly releases is set to originate from China only, with the state probable to be the world’s main wholesaler of oil by 2025 (Naudé, 2011). The development in CO_2 will be determined not merely by the rising affluence and increasing request from increasing industrialized giants like India and China; but also from the necessity to meet the still as yet unmet request of about 1.5 billion people in the world who shorts admission to electricity and growth as well as the most of those who live in Sub-Saharan Africa (SSA) (IEA, 2009).

Developing countries will however, in many cases also be worst affected by climate change. And most of the current industrially generated stock of carbon in the atmosphere has been caused by advanced economies, where most of the technological capability, know-how, human skills and financial resources reside to mitigate climate change and adapt to its impacts (Naudé, 2011).

Green industrial policy

Green industrial policy (GIP) is strategic government policy that attempts to accelerate the development and growth of green industries to transition towards a low-carbon economy. This policy has come about as a result of global concern for climate change and its adverse effect on countries especially in developing countries. Greening, the economy, transforming it to ensure environmental sustainability, is becoming increasingly urgent at the current rates of natural resource depletion. There is an urgent need for support for international cooperation and coordination of green industrial Policy.

Now the dilemma is, if such management is complete, it may imply that industrialized guidelines will face definite global restraints, nonetheless will have to poise universal weights for climate change alleviation contrary to nationwide weights for job making as well as structure. It was renowned that numerous emerging nations have possibly greatly to benefit from carbon-concentrated industrial development, mainly as they face job making as well as providing basic services, comprising electricity and infrastructure construction.

Energy Efficiency and diversification

Energy competence involves expending a lesser amount of energy in construction and consumption. This includes growth of clever networks, developments in constructing energy competence, industrialized energy competence and vehicle competence (Martin, 2010). Energy competence in industrialized procedure can contribute suggestively to condensed GHG releases. Trudeau and Tam (2009) evaluated that energy savings in commerce might contribute to a decline of about 5.7 Gt in CO_2 releases by 2050. Internationally synchronized IP and collaboration in IP is essential since emerging nations can decrease their industrialized releases suggestively over the small to intermediate term over implementation of presently prevailing best available technologies (BAT). Prins et al. (2010) for example, accounts that BAT in the steel business is internationally diffused; it will diminish CO_2 releases yearly by about 340 million tons. IPs simplifying knowledge, repetition, accepting and research on a sector-by-sector source will be needed (Trudeau and Tam, 2009). It should be noted that, although improvement in industrial energy efficiency can make an important short-term contribution, it may not necessarily lead to significantly lower energy demand or reduced GHG emissions.

Moreover, energy divergence necessitates strong IP creativities to upsurge the part of non-fossil fuels in energy demand. Energy change would mean better usage of renewable energy sources clean energy (Simmons, 2014). Such variation is appreciating great importance in numerous nations, not only founded on issues on climate change, but also on energy safety and the likely chances it might grip for industrial development and job formation.

IP and trade policy

In recent times, the concern about environmental impacts has gone beyond relying on existing national regulation because international markets are increasingly demanding environmentally sound products (ITTO, 2005). Most international certification schemes provide options to consumers to choose products, which have been sourced that are deemed to be managed sustainably (Brundtland, 1987). Therefore, life cycle thinking has become a key focus in environmental integrated product policy and an effective integration of this concept in Ghana is considered as a critical success factor for a more sustainable industry.

The research on the links between trade rules and climate change action has mostly been concerned with how far climate change action is constrained by current trade rules pertaining, for example, to border tax adjustment (Horn and Mavroidis, 2011), subsidies (Green, 2006), and exports of natural gas (Levis, 2012). It is argued that only radical technological progress can reconcile climate change goals with the development and energy aspirations of humanity (Mattoo and Subramanian, 2012). Generating technological progress requires deploying the full range of policy instruments (Mathew, 2015).

Considering IPs to foster a low-carbon economy will have important repercussions for trade and Foreign Direct Investments (FDI) and hence trade policies. Bilateral Trade Agreement (BTA) currently appears to be the most favored approach. This approach makes industrial and trade policies consistent. Whalley and Dong (2008) deliberated some of the problems involved in the use of BTAs to influence releases. Initially, they noted that it is development instead of trade, which is the main releases donor. In addition, releases vary more considerably between nations than merchandises, posing the issue of whether skill procedure must distinguish against merchandises, or nations and struggle with the non-discrimination articles of the World Trade Organisation (WTO). In addition, WTO based rate events will probably have minor influence on releases since most are in a minor amount of areas where production is not directly transacted, for example electricity generation and transportation. Moreover, it is problematic to describe and decide on what might be viewed as ecologically subtle goods and services to indulge disjointedly in trade. Additionally, the management of BTAs founded on the carbon-content of importations will be an expensive procedure and challenging to execute. Lastly, Whalley and Dong (2008) also indicate the hazard that when BTAs are used that management might want to involve in additional tactical trade strategies to try and counterbalance other apparent causes of modest shortcoming, which could message a novel period of receding from permitted universal trade to isolationism. In other words, BTAs might be misrepresented for protection. Therefore, in the milieu of climate change IPs must watch as touching being appropriated by planned trade rules because of misappropriation of BTA. Cautious arrangement with trade is necessary; furthermore, the drawbacks once more highlight the significance of internationally synchronized IPs.

CONCLUSION AND RECOMMENDATIONS

This paper aim to clarify the need for IP because of climate change and to regulate its insinuations for the one district one-factory industrial policy in Ghana. Therefore, this paper made the case that the carefully chosen industrial policies (IPs) are required to manage such development amidst the climate change issue on one district one-factory industrialized procedure in Ghana. Numerous emerging nations might profit from this green evolution, if they can organize satisfactory and suitable replies through IPs.

Four key issues international coordination, green industrial policy, energy efficiency and diversification and trade policies were discussed and the key conclusion was that in the situation of weather change the most significant precondition for dodging drawbacks is that IPs require better global organization and collaboration than what they had in the past. Dealing with climate change is an economic necessity because climate change impacts are very likely to increase and are very likely to impose costs, and these costs will increase over time if critical measures are not put in place. A coordinated international response can drive down the cost of mitigation compared to doing this in isolation in Ghana. This has been the principal issue in this research. This work recognized a few problems, comprising the circumstance that emerging and progressive economies experience diverse purposes and issues in low-carbon industrial development. For emerging nations, job formation as well as the addition of energy to their inhabitants are important; for progressive economies, it is job formation and energy safety. IPs for low-carbon industrial development requires be intending and synchronizing about these necessities. Therefore, IPs must have diverse long and short-term objectives. Industrial development is a main carter of economic development and expansion as well as it is a main basis of GHG, which donates meaningfully to worldwide climate change. The benefits of industrialization are needed nonetheless in light of the probable economic influence of climate alteration, industrial development wants to take place sustainably.

More investigation is required to extend the insinuations for IPs in Africa particularly Ghana where agriculture is the major This paper recommends that since the basis of livings to a mainstream of the populace, as stated by most estimations, will be sternly affected by global warming. Therefore, the best reply in Africa might be to endorse Technical Vocational Education and Training (TVET), job-concentrated development, the rollout of communal safekeeping nets, and the reassurance of free enterprise. This would necessitate socio-political steadiness and sustained developments in governance from African administrations. Eventually what would be essential if the climate change issue is to be believably accepted is that global harmonization of IPs would cause a change in the nature of growth collaboration moving it from donor-focused support concerning growth conglomerates that are steady with indigenous needs, circumstances and capabilities, as well as that gives emerging nation legislators, through their IPs, a driving-seat role in their nations' growth.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Household Willingness to Pay for Improved Solid Waste Management in Shashemene Town, Ethiopia

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This study tried to investigate urban community's willingness to pay for improved solid waste management. Double Bounded Dichotomous Choice technique was used to examine household's willingness to pay for improved solid waste management. The collected data further analyzed Bivariate probit and logistic regression models to investigate the mean and factors determining willingness to pay for solid waste management. A random sampling technique produced surveys from 190 households. Majority of the households indicated that the current solid wastes management is very poor. The econometric result showed that the mean and total willingness to pay from double bound elicitation method was 16US$/household/year and 590,473.22US$/year respectively, while the mean and total willingness to pay from open ended elicitation method were computed at 14US$/year and 524,306.8US$/year. The mean annual willingness to pay for solid waste management from double bound elicitation method was greater than from open ended elicitation method. Households' age, size, income, education and amount of solid waste generated as well as bid value, were key determinants of solid waste management improvement. Hence, policy makers should target double bounded elicitation method than open ended elicitation method of eliciting the willingness to pay for solid waste management improvement.

Key words: Willing to pay, logistic regression, Bivarate profite, contingent valuation method (CVM), solid waste management (SWM).

INTRODUCTION

Cities in developing countries are facing increasing generation of waste (Begum et al., 2007) and accompanying problems associated with waste collection and disposal (Begum et al., 2007) resulting from urbanization process that brings a lot of problems in most third world countires (Kwabena and Danso-Abbeam 2014). In Africa, it is estimated that currently the rate at which solid waste is growing in urban areas is much

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faster than the urbanization itself (Hoornweg and Bhada-Tata, 2012). Likewise, according to UNESC (2009), urbanization with poor waste management practice, especially widespread disposal of waste water bodies dumping inside the road and uncontrolled dump site magnifies the problem of low sanitation level across the African countries. The problems are aggravated by high amount of waste generation, shortage of waste disposal sites, lack of waste collection by municipality offices, and less attention and poor disposal habits by dwellers (Banga et al., 2011). As evidences have shown that the global populations of urban residence continue to grow significantly within the last decades, it was reported that with about 30% of world population living in urban areas in 1950s, the figure is projected to reach 66% by year 2050 (United Nations, 2015).

In the last few years due to rapid natural population growth, high rural-urban migration and rising per capita incomes, cities in Ethiopia are growing fast (FDRE PCC, 2008). But the technology, technical knowhow, financial capacity, and understanding of the community required to properly manage solid wastes are not sufficiently available (Ali, 2001). As a result, most urban area in Ethiopia lack of financial resources and institutional power to supply basic infrastructures and services such as, the way how to manage solid wastes for the dwellers (Chakrabarti and Sarkhel, 2003). SWM is a daily routine that is continuous and never ends. As each day passes, it brings new task of streets to sweep, waste to collect, waste loads to haul and safely to dispose (Onukogu et al., 2017).

In order to ensure conducive urban environment for wellbeing of urban dwellers, a solid waste management services must be fulfilled (Muhdin et al., 2016). In Ethiopia, all urban level governmental bodies are taking the responsibility for SWM services (Muhdin et al., 2016), but these services are only focusing on collection of wastes from dumping areas (Muhdin et al., 2016). At present, Shashemene town municipality has a single truck and also allowing jobless youths to participate in waste management system via door to door collection by their push cart. Similarly, the households are expected to store wastes on their plastic bags or other temporary storage inside the home and hand over to these private waste collectors; (that is, community based approach). But what is actually observed is different; that is, there are wastes which are dumped on the road, burning inside the village and throwing in sewerages by the households. This implies that, solid wastes released from home are not properly managed by the households. Additionally, most municipalities have been disposes urban wastes improperly on open land near different agricultural lands. As a result, different waste debris has been carried away by the wind blown from the disposal sites and thereby trashes surrounding farms and homesteads.

Most studies are carried out on solid waste management practice improvement by given more focuses on waste generation rate of urban areas (Lemma, 2007; Melaku, 2008) and even special emphasis is given to the determinants of recycling of solid wastes; which is revolving on developed nations (Sterner and Bartelings, 1999). But such assessments do not guarantee to conclude about the factors affecting households' willingness to pay for improved SWM.

Likewise, previously some studies have been conducted on identifying SWM constraints and most of them reached different conclusions for the same research ideas (Tadesse, 2006; Dagnew et al., 2012; Amiga, 2002), that required further study. To this effect, it is impossible and does not guarantee to deal with the wide world urban areas by only taking the studies conducted in a certain specific area.

In addition, most of the studies have been conducted at the regional level and sub cities of Addis Ababa - Ethiopia. So, this work attempts to fill the research gap on SWM existing at zonal level and to identify factors mostly affecting this micro level. On top of these, this type of study has not been ever conducted in the selected area, and the municipality also has not filtered or proved information about the problem of SWM. Hence, this study is timely to find the real factors affecting households' willingness to pay for improved SWM practice of the town and tries to provide feasible solution for the identified problems. For that reason, based on an in-person household survey, the objectives here are (i) to assess the existing situation of SWM, (ii) to estimate households' WTP for improved SWM using the contingent valuation method (CVM) and (iii) to identify socioeconomic determinants of households' WTP for improved SWM.

MATERIALS AND METHODS

Site description

This study was carried out in Shashemene town. Shashemene is the zonal city of west Arsi zone; geographically; the town is located at 7°11'09"N to 7°13'19" N latitude and 38°35'02" E to 38°37'05" E Longitude. It is located within the Great Rift Valley system and is close to the lake and holiday resorts of Hawassa town, Langano and the Shala-Abiyata Park. Its altitude ranges from 1,672 - 2,722 m a.s.l. Mount Abaro is the highest point 2, 580 m a.s.l. The total population of Shashemene was estimated around 150,000 by 39,474 households (CSA, 2010). Figure 1

Data collection and sampling method

Multistage stage sampling technique was employed for sample household selection to collect the necessary data for the study. In the first stage, Shashemene town was purposively selected. The selection of the town was made on the account that it is the 2nd center of commercial area next to Addis Ababa. In the second stage, three peasant associations (PAs) namely *Abosto*, *Arada* and *Didaboke* were selected on the basis of population number and commercial activities. Lastly, random sampling method was employed to select the sample households. Total number of households (HHs) in the selected peasant association was 10935. Using Equation 1 for sample size determination given by Israel

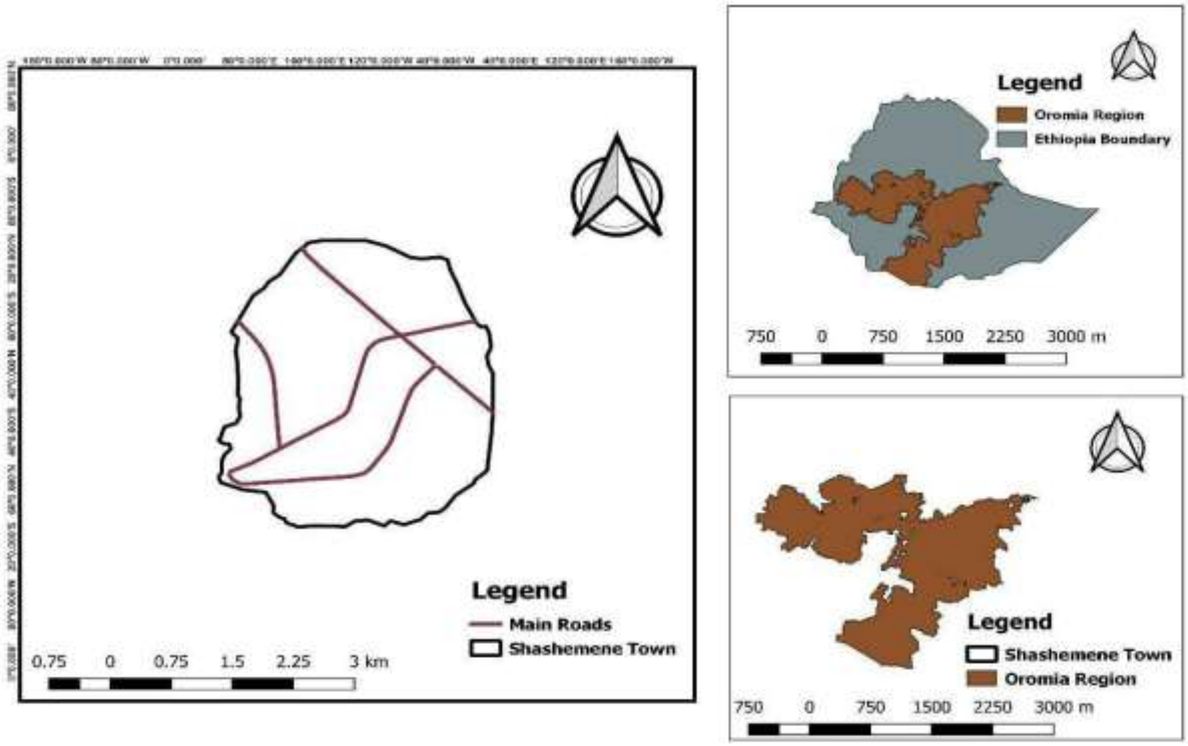

Figure 1. Map of the study area

(1992), a sample size of 199HHs was obtained with a sample fraction (k) of 0.027 at 7% significant level.

$$n = \frac{N}{1 + N * e^2} \quad (1)$$

Where: n is sample size, N is total households and e is the significance level.

A semi-structured questionnaire was prepared. The questionnaire was pre-tested in 2 households from each PA and 3 experts from Shashemene municipality workers and 6 from solid waste collector cooperatives, respectively. The questionnaire was amended based on the feedback from a pre-test. In the Double-bounded dichotomous choice elicitation format, a respondent was asked about his/her WTP of a pre-specified amount of initial bid during pilot survey for the proposed SWM practices.

Contingent valuation method (CVM) in the form of double-bounded dichotomous choice elicitation method (Haab and McConnell, 2002) with open ended follow up question was also employed to explore households' WTP for improvement of SWM (Haab and McConnell, 2002). The double-bounded dichotomous choice format (yes-no, no-yes responses) (Arrow et al., 1993) makes clear bounds on unobservable true WTP and the yes-yes; no-no response sharpens the true WTP (Haab and McConnell, 2002) The double-bounded dichotomous choice format also helps to elicit more information about respondents' WTP than single bounded format (Arrow et al., 1993; Hanemann et al., 1991).

Bid design scenario

The payment vehicle was monthly garbage fee to be paid to the service provider (Cameron et al., 2002). Based on the scoping survey and pilot survey, five different bid prices were determined as birr 30, 35, 40, 45 and 50. Using these initial bids, sets of bids were determined for follow up questions based on whether the response is "no" or "yes" for the initial bid (Table 1). If the respondents were willing to take the offered initial bid, the follow up bids were 35,40,45, 50 and 55 birr; in case of a "no" response to the initial bid; the follow up bids were 25, 30, 35, 40, and 45 birr respectively.

Given this, the actual survey was undertaken by dividing the total sampled households randomly into five groups. The survey was successfully completed with relatively small number of protest zeros (about 2%). These protesters provided wrong value and after checking for sample selection bias, they were excluded from the data set. The criteria for selecting protest zero were based on the report of the NOAA Panel on contingent valuation (Cameron et al., 2002). According to Cameron et al. (2002) suggestion, respondents are willing to pay the stated amount but if the respondent believes that the proposed scenarios were distributed unfairly; one can refuse to accept the hypothetical choice.

Data analysis

The survey data were analyzed using descriptive statistics and econometric models. The descriptive statistics includes mean, standard deviation, percentages, frequency distribution and graphs.

Econometric model specification

In this research the double-bounded value elicitation question format was chosen to elicit the WTP of respondents for the proposed change and for the purpose of statistical efficiency and consistency. The main advantage of double-bounded over single-bounded format is that it increases the statistical efficiency of CV

Table 1. Bid design.

Lower second bid (LSB)	First bid (FB)	Upper second bid (SUB)
25	30	35
30	35	40
35	40	45
40	45	50
45	50	55

surveys in three ways. Firstly the number of responses will increase. Secondly, even if there may be cases with no clear bound on the responses (the case of Yes-Yes or No-No), it is used to constrain the distribution of WTP. Thirdly there will be clear bound in WTP responses in the case of Yes –No or No-Yes responses (Hanemann et al., 1991; Cameron et al., 2002). In the data cleaning step, from a total of 199 sample households about 190 (95.47%) households provided complete responses and were considered in the analysis. However, the remaining 9(4.52%) households gave incomplete responses or miss elicited and dropped from the consideration. Out of the considered 190 responses, 53 (27.87%) of the respondents have zero WTP. A logistic and bivarate probit econometric model was used to identify factors affecting the probability of willingness to pay and estimate mean willingness to pay for solid waste management respectively. But, before the bivarate probit model was applied to analyze the effect of explanatory variables on WTP, variance inflation factor (VIF) was applied to test the multicollinearity between continuous explanatory variables (Appendix 1). It was computed as:

$$VIF = \frac{1}{1+Ri^2} \tag{2}$$

Where, R_i^2 is the coefficient of determination in the regression of one explanatory variable (X) on the other explanatory variables (X_j). If there is no collinearity between regressors, the value VIF is 1. A VIF value of a variable exceeds 10, which happens when R^2i exceeds 0.90, and that variable is said to be highly collinear (Gujarati, 2004). A contingency coefficient was also estimated to see the degree of association between the dummy explanatory variables. A value of 0.75 or more indicates a stronger relationship between the two variables (Healy, 1984). The contingency coefficient (C) was compute as:

$$C = \sqrt{\frac{\chi 2}{N+\chi 2}} \tag{3}$$

Where C= coefficient of contingency,χ2= Chi-square test and N= total sample size

Logit model regression

The logit (double log) linear regression model was used to obtain the willingness to pay of the households for improved waste management. The logit linear model which is based on the cumulative probability function was adopted because of its ability to deal with a dichotomous dependent variable and a well established theoretical background. Logistic regression is a uni and multivariate technique which allows to estimating the probability that an event will occur; it was not through prediction of a binary dependent outcome from a set of independent variables. To identify the factors influencing willingness to pay for improved waste the maximum willingness to pay question was regressed against socioeconomic characteristics of the household. The logistic (double log) linear regression function for this study can be specified as follows:

$$P_i = \in (Y = \frac{1}{xi}) = \frac{1}{1+e^{-(\beta o - \beta ix\ 0}} \tag{4}$$

Where *Pi* is a probability that *Yi* = 1 (WTP for improved SWM), *Xi* is a set of independent variables, *Y* is dependent variable (Responses of household to willingness to pay question which is either 1 if Yes or 0 if No), *ß0* is the intercept which is constant, *ß1* is the coefficient of the price that the households are willing to pay for improved solid waste management.

Bivariate probit model

Bivariate normal probability density functions are among the familiar bivariate distributions employed commonly by statisticians crucially; they allow for a non-zero correlation, whereas the standard logistic distribution does not (Cameron and Quiggin, 1994). Hence, the bivariate probit model is used in this study to estimate the mean WTP from the double bounded dichotomous choice. For estimation of WTP, the bivariate probit Model is used, that is, double bound Dichotomous choice model takes the following form (Haab and Mconnell, 2002).

The j^{th} contribution to the Likelihood function is given as,

$$L_j (\mu / t) = Pr(\mu_1 + \varepsilon_{1j} \geq t_1, \mu_2 + \varepsilon_{2j} < t_2)^{YN} * Pr(\mu_1 + \varepsilon_{1j} > t_1, \mu_2 + \varepsilon_{2j} \geq t_2)^{YY} * Pr(\mu_1 + \varepsilon_{1j} < t_1, \mu_2 + \varepsilon_{2j} < t_2)^{NN} * Pr(\mu_1 + \varepsilon_{1j} < t_1, \mu_2 + \varepsilon_{2j} \geq t_2)^{NY} \tag{5}$$

This formulation is referred to as the bivariate discrete choice model.

Where μ = mean value for willingness to pay, YY = 1 for a yes-yes answer, 0 otherwise, NY =1 for a no-yes answer, 0 otherwise, etc. and the j^{th} contribution to the bivariate probit likelihood function becomes.

$$L_j (\mu / t) = \Phi_{\varepsilon 1 \varepsilon 2}(d_{1j} ((t_1-\mu_1)/\sigma_1), d_{2j} ((t_2-\mu_2)/\sigma_2), d_{1j}d_{2j}\rho).$$

Where

$\Phi_{\varepsilon 1 \varepsilon 2}$= Standardized bivariate normal distribution function with zero means

Y_{1j}=1 if the response to the first question is yes, and 0 otherwise

Y_{2j}=1 if the response to the second question is yes, 0 otherwise

$d_{1j} = 2y_{1j}-1$, and $d_{2j} = 2y_{2j}-1$

ρ = correlation coefficient

σ = standard deviation of the errors

This general model is estimated using the standard bivariate probit algorithms. Finally, the mean willingness to pay (MWTP) from bivariate probit model was calculated using the formula specified by Haab and Mconnell (2002).

$$MWTP(\mu) = -\frac{\alpha}{\beta} \quad (6)$$

Where α = coefficient for the constant term, ß = coefficient offered bids to the respondent

The data were analyzed using STATA version 11.0 and SPSS version 16.0.

RESULT AND DISCUSSION

Existing situation of solid waste management

As a result of rapid population growth and city's expansion, there are multiple issues of sanitary situation and waste management systems. Even though there have been newly constructed vacuum tankers, wells and garbage containers in the city, sanitary and waste management related issues still remain critical problems. As a result, currently liquid and solid wastes are being disposed in open space without any treatment involvements (Shashemene City Administration, 2016, unpublished). To minimize this problem, the municipality is applying different interventions like employing full time and part time sanitary staffs, giving permission to door to door solid waste collector cooperative members, transporting disposal of solid wastes and putting containers in different areas to improve SWM and creating awareness on environmental cleanliness and public health. Besides, 3 vehicles have been pressed into service: one mini truck, one tipper, one tractor trailer, one J.C.B for lifting of solid waste and carrying of the waste disposal point. According to the respondents, the municipality provides these services but the problem is not solved. Since households were damping wastes from central bins, dust has been placed in residential, market and commercial areas. In addition the container is not placed on time. Only cooperative members take the waste of households since they make payments. However, poor households not able to pay dump the waste nearby river, open space, street, drain and/or burn openly.

According to the Federal Democratic Republic of Ethiopian SWM proclamation no. 513/2007, environmental cleanliness and public health responsibility relied on the shoulder of urban municipality. However, rapid growth of population, urbanization, economic expansion, lack of proper awareness on SWM of households, lack of infrastructures, lake of investors participate in waste management system via door to door collection, financial problems were the main challenging problems in SWM in Shashemene town. The study is also related with what has been found by Solomon (2006) and Dagnew et al. (2012) in Mekelle city; Ashenafi (2011) in Ambo town; Begum et al. (2007) in Malaysia and Banga et al. (2011) in Kampala City, Uganda. Urbanization, economic expansion, lack of proper awareness and generation rate and type of solid wastes are determined by the consumption habits and living condition of each household.

Estimation results from double bounded dichotomous choice

In this double bounded dichotomous choice method, the respondents were subjected to choose between two alternatives: an improved SWM situation with three potential costs (FB, LSB, and SUB) that derive a utility U_1 and the status quo U_0 yielding no improvement in environmental conditions and no increase in cost. Four possible outcomes arise with different probabilities of: (i) both answers are 'yes'; (ii) a 'yes' followed by a 'no'; (iii) a 'no' followed by a 'yes'; and (iv) both answers are 'no'. Assuming that each random term is distributed as a Type I extreme value, then following Hanemann (1991), the following response probabilities are obtained for our model:

$$P(yes - yes) = Pn(YY) = 1 - \frac{1}{1 + e^{(x + \beta SUB + \varepsilon_{\gamma z_n})}}$$

$$P(yes - yes) = Pn(YN) = 1 - \frac{1}{1+e^{(x+\beta SUB\ +\varepsilon_{\gamma z_n})}} - \frac{1}{1+e^{x+\beta FB\ +\varepsilon_{\gamma z_n})}}$$

$$P(No - yes) = Pn(NY) = 1 - \frac{1}{1+e^{(x+\beta FB\ +\varepsilon_{\gamma z_n})}} - \frac{1}{1+e^{x+\beta SLB\ +\varepsilon_{\gamma z_n})}}$$

$$P(No - No) = Pn(NN) = 1 - \frac{1}{1 + e^{(x + \beta SLB + \varepsilon_{\gamma z_n})}}$$

Where FB is the initial bid, LSB is the second lower bid, SUB Upper second bid; $\alpha, \beta, and\ \gamma$ are parameters and Z is the socio-economic characteristics of the respondent n being analyzed (Table 2).

Households' WTP for solid waste management

The respondents were asked subjective questions like what is the maximum amount of money that each household WTP each month for the wastes generated from their home. Accordingly, the mean WTP of the respondents is 31.30 Birr per month per bag. The mean WTP is efficient and valid measure (Bateman et al., 2002). The total WTP of 190 sample respondents was also estimated to be birr 3,728.19 per year with minimum 0 and maximum 85 birr (Table 3). Furthermore, lower numbers of respondents were recorded in the higher bids (Figure 2). Whereas, 26.63% of the respondents were

Table 2. Response of respondents.

Variable	Freq	Percent
Yes -yes	96	50.53
Yes -no	21	11.05
No -no	58	30.53
No -yes	15	7.89
Total	190	100

Table 3. Non- parametric estimation of WTP for SWM.

Range number	Frequency	%
0 -26.66	68	35.79
26.67-43.33	57	30.00
33.34-59.94	46	24.21
59.95-76.55	14	7.37
76.56-93.16	5	2.63
Number of households	190	100
Min	0	
Max	85	
Mean	31.30	

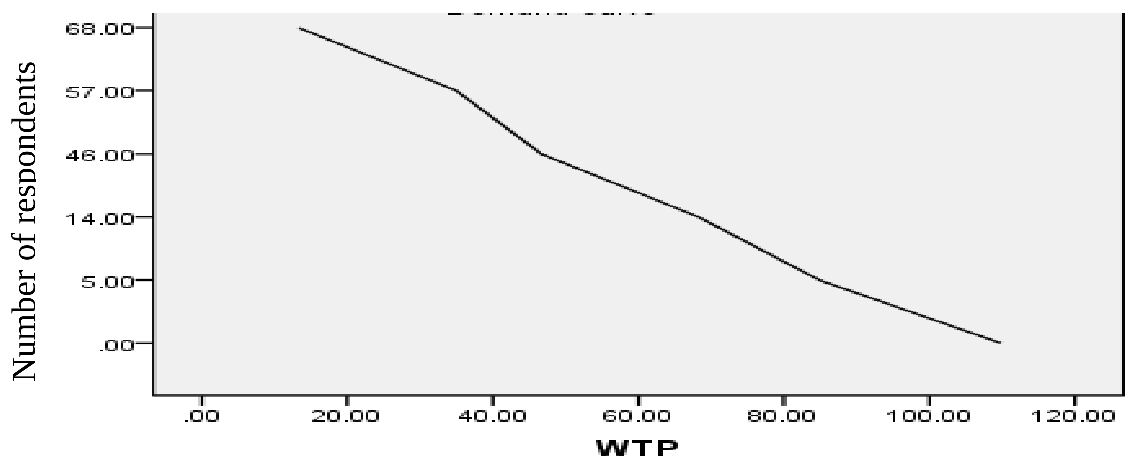

Figure 2. Frequency curve of 190 households' WTP.

given the reasons for not willing to pay for the proposed project (Table 4).

Determinants of households' willingness to pay

Binary choice modeling (logit model) was projected to identify factors affecting households' WTP for SWM and their relationship. Maximum Likelihood (ML) method was employed to estimate the parameters in logistic regression model. Likelihood ratio index has been measured as an indicator of goodness of fit for the logistic regression model. Dependent variable is designed as a dichotomous dummy because of assuming whether the respondent is willing to pay or not. The model is,

$$\log p_i/(1-p_i) = zi = \beta_o + \beta_i X_i + \ldots + \varepsilon$$

Where,

P = 1 if the respondent is willing to pay for improved

Table 4. Reasons for non -willingness to pay by respondents.

Variable	Freq.	%
Positive willingness to pay	133	66.84
Valid zero bidder	53	26.63
(i) Have no extra income but otherwise would contribute	24	12.06
(ii) Don't believe that the SWM improvement programs would bring the changes	29	14.57
(iii) Protest Zero bidder (Rejection of contingent market)	9	3.52
(iv) It is the government's responsibility	5	2.51
(v) Waste management improvement is not important	2	1.005
(vi) It is the responsibility of those who pollute the environment to pay for it	2	1.005
Total	199	100

Table 5. logistic model regression result.

WTP (independent variables)	Coef.	Std.Err	z	P>/Z/	dy/dx
Age	-0.035	0.0155	-2.29	0.022**	-0.0059
Sex	0.386	0.5150	0.75	0.453	0.0670
Household Size	-0.618	0.1826	3.38	0.001***	-0.0747
Income	0.0006	0.0002	2.50	0.012**	0.0001
Marital status	-1.3543	0.5588	-2.42	0.150	-0.1831
Education level.	0.1195624	0.0521	2.29	0.022 **	0.0197
Awareness	1.550271	1.892	0.82	0.413	0.0313
Current waste Collection service	-0.3184	0.4971	-0.64	0.522	-0.0498
Amount of waste generated	0.6182	0.1826	3.38	0.001***	0.1020
Type of solid waste service	0.2017	0.5873	0.34	0.731	0.0346
BID	-0.1148	0.0337	-3.40	0.001***	-0.0189
Cons	0.1857	0.4550	0.41	0.683	
Number of observation = 190 LR chi2(11) = 109.41 Prob > chi2 = 0.0000		Log likelihood = -61.357634 Pseudo R2 = 0.4713			

Note: ***, ** and * significant at 1, 5 and 10% probability levels, respectively

waste management;
Pi = 0 for otherwise;
Xi = independent variables;
β_o= constant term;
β_i = coefficient of independent variables;
ε = the error or disturbance term;
i = 1, 2, 3. . . n

Age and household

Age has a negative significant ($p<0.05$) effect on respondents' willingness to pay for improved SWM (Table 5). Marginal effect also shows that while the ages of the respondents increase by 1%, willingness to pay is reduced by 0.59%. This implies that younger respondents would know and appreciate the value of SWM than the older ones about the negative impacts of solid wastes (Afroz et al., 2006; Afroz and Keisuke, 2009). Household size has also negatively significant ($p<0.5$) effect on WTP. Similarly, marginal effect indicates that all factors keeping constant, at 1% increase of the household size of the respondents; their willingness to pay is reduced by 7.47% because waste management activities are handled by the members of the family and lack of money to outsource such services (Anjum, 2013; Othman, 2002; Jin et al., 2006).

Income

Income has a positive relationship with the households' WTP ($p<0.05$). This indicates that improved SWM is a normal good since its demand increases with income. This implies households with high income are more WTP for the SWM than households with low incomes. Marginal effect indicates while household income increases by 1 Ethiopian birr, WTP for SWM improvement increases by

Table 6. Bivarate probite model result.

Variable	Coefficient	Standard error	z
Bid1	-.075	0.0045	4.43
Constant	3.371	0.1609	3.21
Bid 2	-0.008	0.0044	-1.95
Constant	0.298	0.1519	1.94
ρ***	0.9829	0.0238	
Log- likelihood= -177.69		Likelihood-ratio test of rho=0:	
Wald chi2(2)= 21.59		chi2(1) =33.26	
Prob> chi2=0.000		Prob > chi2 = 0.000	

0.01% (Afroz and Keisuke, 2009; Bamlaku et al., 2015; Dagnew et al., 2012). While Johnson and Baltodano (2004) studies reported that income did not have an effect on the households' WTP for improved water quality improvement.

Education

Education has positive coefficients and significance at $p < 0.05$. An increase in the respondents' year of schooling by 1% will increase their willingness to pay for improved SWM services by 18.31% (Zerbock, 2003; Dadson et al., 2013).

Amount of solid waste generated

Amount of solid waste generated per month per households is a positively significant at $P < 0.01$. Marginal effect estimates show that, by keeping the influences of other factors constant, a one sack solid waste amount increases in the probability of households' willingness to pay by 10.20% (Dagnew et al., 2012).

Bid values

Bid values have negative coefficient and are significant at $p < 0.01$ for the follow up question. As the bid amount increases, willingness of respondents to accept the scenario is low and that is consistent with the law of demand. Likewise, as one more "yes" response given for the second bid, it results in a decrease of WTP by -0.0189 marginal effects.

Bivariate probit model

The analysis was conducted using seemingly unrelated bivariate probit model. The result revealed that the initial bid and the second bid have the negative signs and statistically significant which is expected. This implies that higher initial bid and second bid lead to lower probability of accepting the bid offered. In this fitted seemingly unrelated bivariate model, the coefficient of correlation (ρ) of the error terms is positive and significant ($p < 0.01$) for both payment vehicles. Besides, the correlation coefficient of the error term is less than one which implies that the random component of WTP for the first question has no perfect correlation with the random component from the follow-up question (Table 6).

Double-bounded contingent valuation model is used to estimate the mean WTP and its determinants. There are two options of independent models which can be used to estimate mean WTP. The models are bivariate model with no covariates (WTP checked against the offered amount) and bivariate model with covariates (WTP for SWM against socio-economic factors). Thus, before deciding on which model to apply, it seems important to compare the results which would help to capture the true behavior of people that is expressed through their preferences. Cameron et al. (2002) indicated that, the model which runs with determinant factors to estimate mean WTP are more preferred for its high marginal value accuracy estimation for environmental changes. As a result the mean WTP value of improved SWM ranged from 44.95 to 35.25 ETB per household per month, for the initial bid (Fbid) and the follow up bid (Sbid), respectively. In order to choose the appropriate mean WTP among the two bivariate estimates, it was looked into the data and the total amount for the YY and NN responses accounted for about 81.06 % of the total responses. This means that the 2nd bid amount was closer to the unobserved true value of the individual. For example, if the first random bid for the individual was 30 ETB and the respondents accept the first bid then the 2nd bid becomes 35 ETB; again, if the respondents accept the second bid. This indicates that the respondents' true WTP is greater than or equal to 35 ETB so the 2nd bid will be a better estimate than the 1st one. The same is true for NN answer. Even for the rest 18.94% of the NY and YN responses, both the first and the second bid amounts will have equal chances to be closer estimates of the true value; hence, using the second estimate of the double bounded bivariate model to calculate as mean willingness

Table 7. Average and aggregate willingness to pay of households for SWM.

Total HHsY	Expected HHs to have a protest zero (A[1])	Expected HHs' with Valid Responses (B[2])	Mean WTP (C[3])	Mean WTP per year	Aggregate Benefit Per year (D[4])
39474	1784.22	37689.78	35.25	423	15,942,776.94

[1](A) 9(4.52 %) of our 199 sampled households were protest zeros. We excluded those protest zeros from further analysis after we have tested for sample selection bias. So A is the expected number of households which are expected to protest for the proposed project. It is calculated by multiplying the percentage of sampled protest zeros (4.52 %) with the total population 39474.
[2] (B) Is Y-A which is the total households in the study area which are expected to have a valid response
[3] The mean WTP calculated from the maximum amount of Birr that a household could pay for SWM
[4] Is mean multiplied by the number of total households which are expected to have valid response (B*Mean WTP)

to pay for SWM improvement.

Aggregate WTP for improved solid waste management

As it is indicated in Table 7, the aggregate WTP was calculated by multiplying the mean WTP by the total number of households who were expected to have a valid response in the study area. Following this, in this study the aggregate WTP for improvement of SWM practices was computed at 1,328,564.75 ETB/month.

CONCLUSION AND POLICY IMPLICATION

In rapidly growing cities in developing countries, solid waste is a major source of concern due to lack of appropriate planning, inadequate governance, resource constraint, and ineffective SWM. According to UNEP (2004), particularly in developing countries solid wastes generated by cities have become an environmental and public health problem everywhere in the world. This research was conducted on randomly selected sample of 190 households, and used eleven explanatory variables in the regression models based on the degree of theoretical importance and their impact on WTP. Logit and seemingly bivarate probit models were used to identify the determinants and mean willingness of households for improved SWM system using CVM. To improve solid waste collection system of the town, on average the households are willing to pay 1,328,564.75 ETB per month for wastes collection service.

A key policy implication of the results of this study is that policy makers can choose from a set of scenarios, which include different levels of attributes and WTP estimates for each attribute, to design an improved solid waste management project for Shashemene town. Policymakers have to consider the investments required, the service outcomes and the amount households are willing to pay for improved services. In addition, policymakers need to be aware that socio-economic characteristics and quality of waste collection services will influence the willingness to pay for better waste management. Without knowing the costs of providing various service improvements, we cannot recommend specific improvement measures. What we can state with clarity, nonetheless, is that survey households express a clear preference for improvements in waste management services and have a considerable willingness to pay for SWM practices.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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