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International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Flood hazard assessment of River Dep floodplains in North-Central Nigeria

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Flood is a recurring event that leads to hazards. The probability of a flood occurring is normally investigated followed by flood hazard mapping which defines the areas that are at risk of flood inundation. This study carries out flood hazard assessment for the flood prone areas within the low-lying flat river valley of the River Dep watershed using Remote Sensing (RS) and geographic information system (GIS) for 2-year to 1000-year return periods, with regards to inhabited areas and other land uses that will be affected. Result shows that the most affected land use within the floodplain is agriculture with inundated area ranging from 68.82 to 146.10 km^2. Low to medium flood hazards predominant dominate the floodplain with area extent increasing from 112.2 to 140.75 km^2 for low hazard and 35.65 to 163.65 km^2 for medium hazard. High hazard is mainly within the deep part of the floodplain with minimal area extent of 4.11 km^2. The study recommends low hazard areas to be used for irrigation farming and early rainy season farming, medium and high hazard areas for irrigation farming only while low, medium and high hazard areas for the 100-year flood should be avoided with respect to construction of residential or commercial structures. Generally areas close to rivers should be avoided for rainy season farming and residential or commercial development.

Key words: Flood hazard, remote sensing, geographic information system (GIS), land use, land cover.

INTRODUCTION

Hazard is defined as a 'potentially damaging physical phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation' (Damayanti, 2011). Alkema and Westen (2005) defined flood hazard as 'the chance that a flood event of a certain magnitude will occur in a given area within a given period of time'. Each hazard is characterised by its location, intensity, frequency and probability. Flood hazard can be described by different parameters including flood extent, water depth, flow velocity, duration and the rate at which the water rises, where flood depth, velocity and duration are important factors in flood damage (de Moel et al, 2009). While flood hazard is the impact of flooding on development and people, the velocity and depth of floodwaters greatly affect personal safety and damage to infrastructure and agricultural lands (Floodplain Development Manual). The manual suggests that at velocities of over excess of 2 m/s grass and earth surfaces begin to scour affecting stability of foundations,

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and depths of over 2 m with less velocity can cause damage to light-framed buildings.

Catchment flood hazard assessment focuses on the catchment as a whole and looks at how the different characteristics of the catchment integrate to contribute to flooding within the floodplains. There is a yearly occurrence of floods of different severity within the River Dep floodplains resulting in loss of human lives, destruction of flood infrastructure, livestock and crops. Flood depth and velocity affect agricultural activities within the Dep floodplain including harvest and transportation of crops within the area. During the rainy season, the farms become submerged in floodwater which can be over 1 m in depth, sometimes taking several days to recede and resulting in destruction of submerged crops.

The inhabitation and use of the floodplains results in encroachment into a land that should be left to the natural elements, posing a great danger to the inhabitants and users, and high risk of destruction and loss of investments and lives. People living within the River Dep floodplains can still enjoy the agricultural benefits that it provides and yet avoid the hazards that come with floods. This can be achieved by ensuring that man's activities do not conflict with the natural occurrence of flooding by adequately planning the use and management of the floodplain. Though conventional traditional methods can be used for flood hazard assessment, the use of remote sensing and geographic information system techniques have been suggested to provide quick, efficient and effective results as investigated and documented by Balanova and Vassilev (2010), Damayanti (2011), Kafle et al. (2006), Salimi et al. (2008), Ahmed et al. (2010) and others. This study is aimed at carrying out flood hazard assessment for the flood prone areas within the low-lying or flat river valley of the watershed with regards to land uses that will be affected. Flood hazard maps for some extreme flood events will be analysed and the affected land uses estimated.

Study area

The Dep River Basin lies between latitudes 8°00'00"N to 9°20'00"N and longitudes 8°20'00"E to 9°35'00"E as shown in Figure 1. It falls within the Lower Benue River Basin Development Authority in North Central Nigeria. The flood plain is within the relatively flat river valley with elevations between 78 to 200 masl. The land within the area is predominantly used for agriculture.

MATERIALS AND METHODS

Softwares

1. ERDAS Imagine 9.2 for remote sensing analysis.
2. ArcGIS 9.3 for GIS analysis. It has the capability of accepting compatible add-on extensions such as the HEC-GeoRAS.

Satellite data

30 m × 30 m resolution Landsat ETM image of Dep River watershed was downloaded from Global Land Cover Facility. It is the only one available for the complete study area. Date of acquisition is 02/11/2001.

Flood hazard assessment

Flood hazard assessment was carried out by assessing the impact of flood depth and flood velocity where deep inundating water and high velocity were classified as the destructive force, deep inundating flood with low velocity as less destructive and shallow inundating water with high velocity as more destructive (Damayanti, 2011). The classification of flood hazard according to depth by Cooper and Opadeyi (2006) and the relationship between flood depth and flood velocity established in the Floodplain Development Manual were taken into consideration.

The following criteria were used by multiplying the depths and the velocities to assess flood hazard:

Level 1: Shallow water and low velocity
Level 2: Shallow water and medium velocity or deeper water and low velocity
Level 3: Shallow to medium or deep water with high velocity or deep water with medium velocity.

The different categories of velocities and depths are tabulated below for the 100-year flood:

Table 1 implies that the threshold for high hazard was set at 1.4m of flood inundation depth and 2m/s of flood velocity.

Flood hazard analyses were carried out for 2, 5, 10, 20, 50, 100, 200, 500 and 1000-year floods, with more emphasis on the 100-year flood, using flood inundation maps previously obtained by Daffi (2013). The map was overlain on the settlement map of the study area to view those that will be affected by flood of these return periods. It was also overlaid on the Landsat land use classified map to view and analyse the land uses that would be inundated by the floods.

RESULTS AND DISCUSSION

Assessment of flood inundation on settlements

Figure 2 shows the flood inundation extent on a 3-D map of the study area. It shows the floodplain is within the low lying river valleys of the Dep River.

Overlaying the 100-year flood inundation map on the settlement map showed that about four settlements are likely to be affected by the 100-year flood as seen in Figure 3.

Ground validation however, showed that of the four settlements seen to be within the flood area, only one settlement called 'Wuse' is under risk of inundation from the flood because of its proximity to the adjacent river.

Assessment of flood inundation on land uses

Overlaying the flood inundation extent map on the land use land cover classification map gave an indication of the area and percentage area inundated by the 100-year

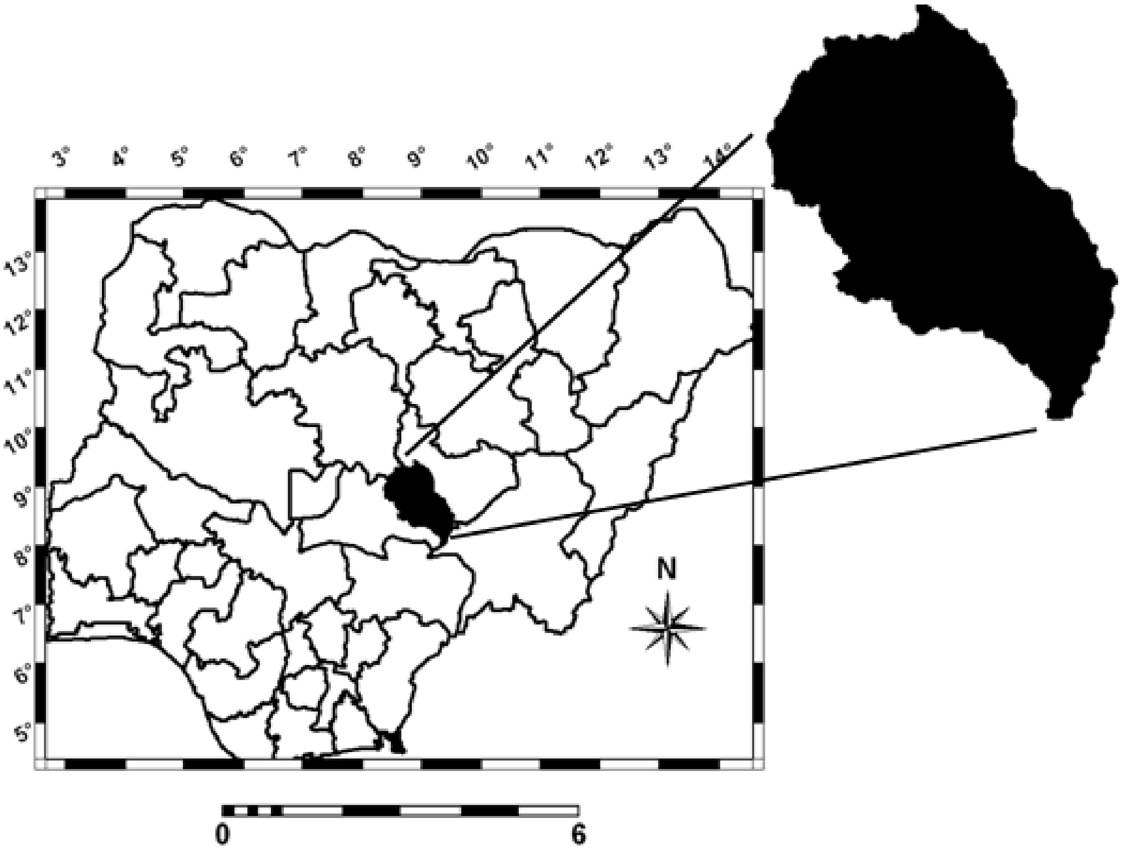

Figure 1. Map of Nigeria showing river dep basin.

Table 1. Flood hazard classification based on flood depths and flood velocities.

Flood depth (m)	Flood velocity (m/s)	Hazard classification	Indicators
0 – 1	0 – 1	Low Hazard	Unlikely loss of life, minor increase to existing flood levels, able-bodied adults can wade to safety with little difficulty
1 – 1.4	1 – 2	Medium Hazard	Possible loss of life, significant increase in flood levels with respect to crops, roads and buildings.
1.4 – 11.86	2 – 3.52	High Hazard	Probable loss of life, major increase to existing flood levels with respect to crops, roads and buildings.

flood shown in Table 2.

Of the total land area of the floodplain, generally shrubs/scattered trees make up the highest land cover class inundated by floodwaters with percentage area of between 46.4 to 46.5% for the 2-year and 1000-year floods respectively. This is because the areas closest to the river, most especially around the confluence of River Dep and River Benue, are made up of dense shrubs and trees and some of the areas are even impenetrable. There was a general increase of 77.28 km^2 or 52.9% for the agricultural land affected by flood from the 2-year to the 1000-year floods.

Also, for all floods agricultural cultivated land is the land use that is significantly affected with an area of 119.86 km^2 for the 100-year flood. A lot of dry season (irrigation) farming takes place within the floodplain which is commonly referred to as 'fadama'. This is the most important land use within the floodplain.

Bare surface/degraded land is the land cover that is least affected by the flood with area of 1.57 km^2 or 0.6% for the 100-year flood. This is because there are hardly any bare surfaces available within the floodplain; the land is mostly cultivated or covered with shrubs or trees because of the swampy nature of the area.

The remaining 6.4% or 16.62 km^2 is made up of water bodies and rock outcrops where the rock outcrops are mainly within the upper parts of the Dep River catchment which mainly make up the source of the river.

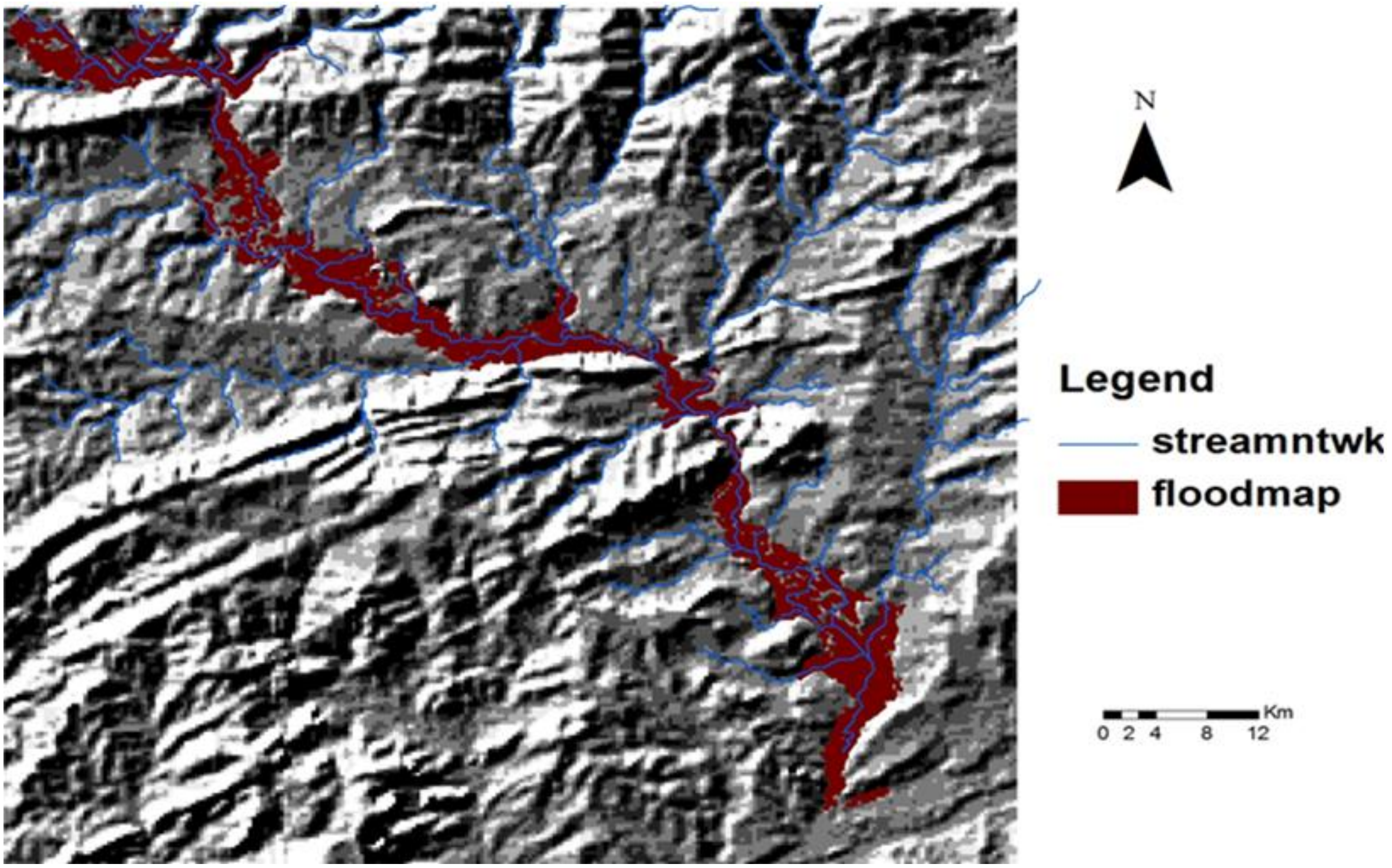

Figure 2. Flood inundation extent on 3-D map.

Generally, the land use that is more prone to flood hazard is agriculture and the worst affected land cover is shrubs and scattered trees.

Flood hazard with respect to flood velocities and depths

Figure 4 shows the flood hazard areas within the Dep River catchment with sections of flood areas for different return periods. These are within the low lying and flat parts of the catchment. The flood hazard classification for the different return periods is shown in Table 3.

The floodplain is majorly inundated by low to medium hazard flood with an area of 105.4 and 150.1 km^2 respectively for the 100-year return period while high hazard flood covers 5.82 km^2. This agrees with the result of a similar study by Damayanti (2011) which showed the area studied to be mostly of high to medium hazard. A marked increase of 145.7 km^2 was observed for medium hazard (71.28%) and high hazard increased by 12.87 km^2 (93.94%). This means that as the return periods increased, the hazard level of the floods was also increasing significantly.

Considering the problems of lack of institutional and infrastructural measures to solve the problem of flooding within the Dep River floodplains, the flood hazard analysis carried out from this study will greatly enhance the suggestion of solutions to the incessant flooding and its effects within the basin. This is because the extent of the area that flooding will affect has been determined by this process thereby locating the critical areas which should be avoided and left for flood waters or used with proper management with regards to how and when to use them.

CONCLUSION AND RECOMMENDATIONS

The most affected activity within the floodplain is agriculture with area inundated ranging from 68.82 to 146.10 km^2 for 2-year to 1000-year return periods. Low to medium flood hazards predominate the floodplain with maximum area of 105.7 km^2 for low hazard and 204.4 km^2 for medium flood. High hazard is mainly within the deepest parts of the floodplain.

It is recommended that:

1. The low hazard areas can be used for irrigation farming and early rainy season farming starting between

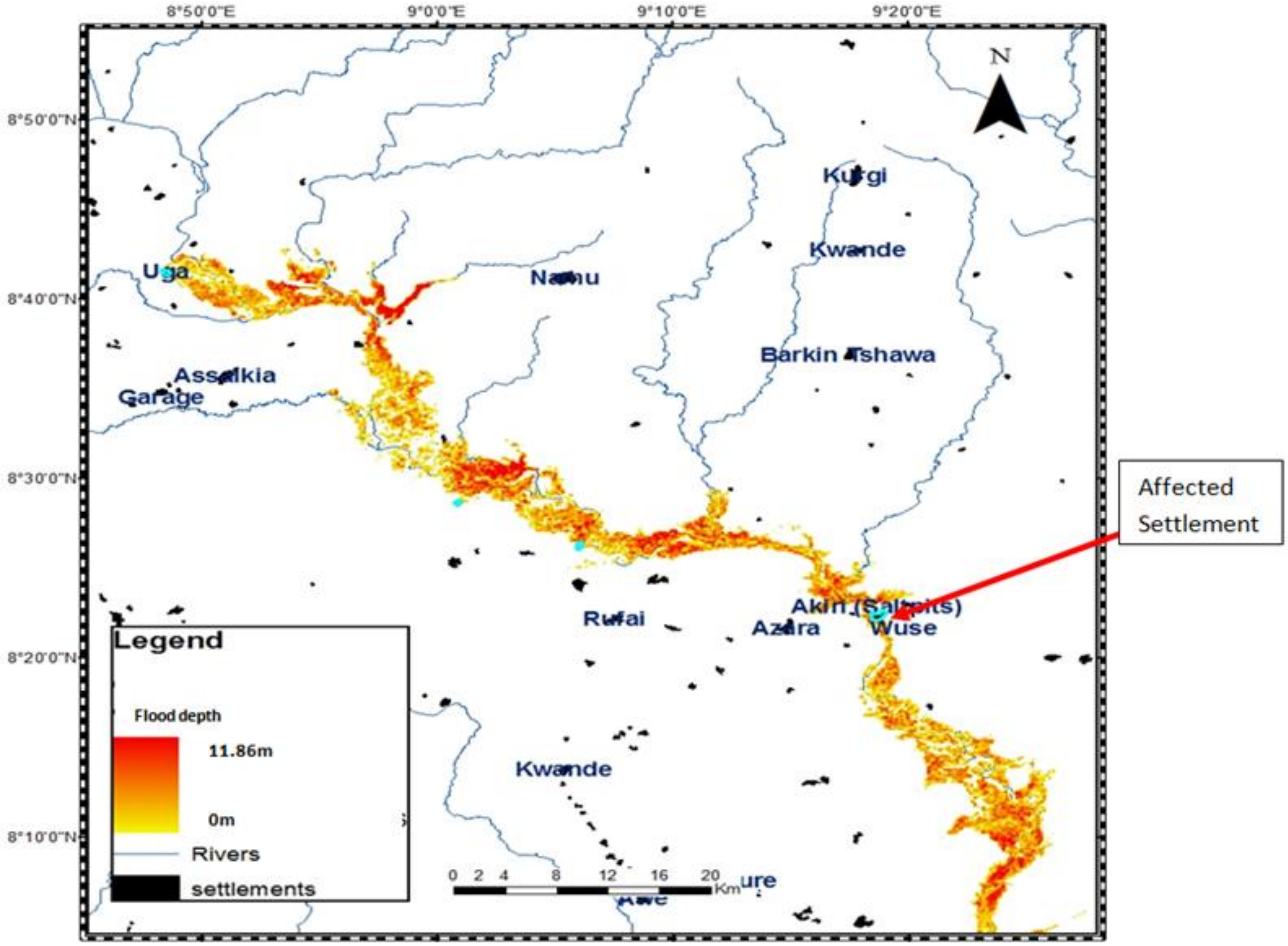

Figure 3. Flood inundation map showing affected settlement.

Table 2. Percentage and area coverage of land use land cover classes inundated by different floods.

Land use land cover	Area of Inundation (km^2)								
	TR-2	**TR-5**	**TR-10**	**TR-20**	**TR-50**	**TR-100**	**TR-200**	**TR-500**	**TR-1000**
Bare/degraded lands	1.01	1.12	1.26	1.37	1.49	1.57	1.67	1.71	1.76
Water bodies	9.28	10.71	11.68	12.54	13.62	14.50	15.37	16.44	17.09
Rock outcrop	1.26	1.44	1.56	1.78	2.00	2.12	2.27	2.42	2.56
Scattered cultivation	68.82	83.19	92.53	101.35	111.80	119.86	128.13	138.23	146.10
Shrubs/scattered trees	69.55	84.25	94.01	102.83	113.90	122.00	129.46	139.35	145.88
Total	149.9	180.7	201.03	219.87	242.8	260.06	276.9	298.15	313.39

March and first week of April or as indicated by the time of rainfall for any particular year.

2. The medium and high hazard areas can be used for irrigation farming only.

3. All the hazard areas for the 100-year flood should be avoided with respect to construction of residential or commercial structures.

4. Generally, areas close to rivers should be avoided for rainy season farming or any other activities during the rainy season.

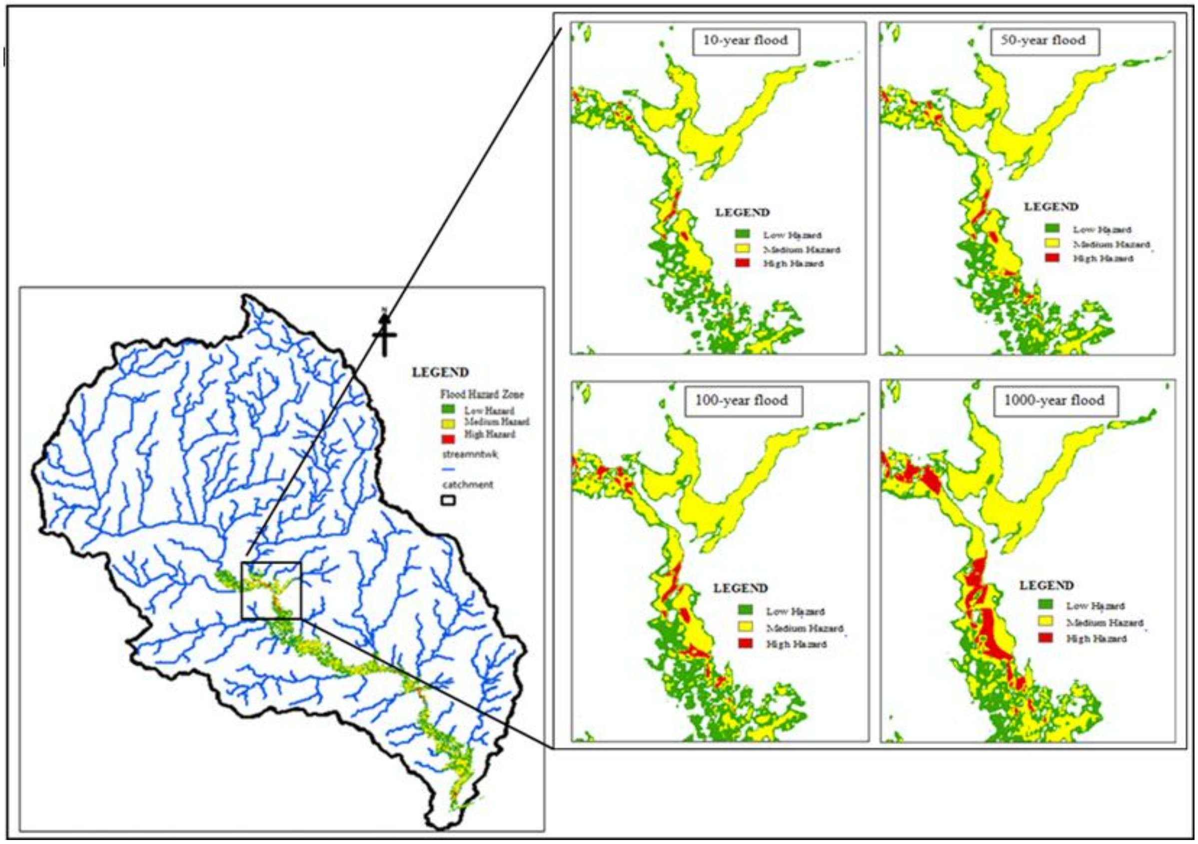

Figure 4. Flood hazard classification for different floods.

Table 3. Flood hazard classification for different return periods.

Hazard	TR-2	TR-5	TR-10	TR-20	TR-50	TR-100	TR-200	TR-500	TR-1000
Low hazard (km^2)	88.7	99.2	103.5	105.5	105.7	105.4	104.1	100.7	97.2
Medium hazard (km^2)	58.7	79.8	95.9	112.6	133.9	150.1	166.4	188.2	204.4
High hazard (km^2)	0.83	1.22	1.49	2.09	3.98	5.82	7.79	10.88	13.70

5. More detailed flood hazard mapping can be carried out with high resolution satellite data like QuickBird or IKONOS.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Ahmed B, Kaleem MS, Butt MJ and Dahri ZH (2010). Hydrological modelling and flood hazard mapping of Nullah Lai. Proc. Pak. Acad. Sci. 47(4):215-226.

Alkema D, Westen C (2005). Flood Hazard and Risk Assessment. Refresher Course on Geo-Information for natural Disaster Reduction in Easter Africa. Makerere University, 12- 23 September.

Balabanova S, Vassilev V (2010). Creation of Flood Hazard Maps. BALWOIS 2010 - Ohrid, Republic of Macedonia.

Cooper V, Opadeyi J (2006). Flood Hazard Mapping of St. Lucia. Final Report for the Caribbean Development Bank.

Daffi RE (2013). Flood Hazard Assessment for River Dep Catchment Using Remote Sensing and Geographic Information System Techniques. Ahmadu Bello University Zaria. PhD Dissertation. Unpublished.

Damayanti F (2011). Hydrodynamic Modeling for Flood Hazard Assessment inTelemoyo Catchment Central Java, Indonesia. Unpublished. M.Sc Thesis. Gadjah Mada University and University of Twente. The Netherlands.

De Moel H, van Alphen J, Aerts JCJH (2009). Flood maps in Europe – methods, availability and use. Nat. Hazards Earth Syst. Sci. 9:289-301.

Floodplain Development Manual: The management of flood liable land. Appendix L - Hydraulic and hazard categorisation. www.environment.nsw.gov.au/.../**flood**plains/18_**flood**_manual.pdf

Kafle TP, Hazarika MK, Shrestha KG, Prathumchai K, Samarakoon L (2006). Integration of remote sensing and GIS with flood simulation model for flood hazard mapping in the Bagmati River, Nepal. New Technol. Urban Saf. Mega Cities Asia, pp. 257-267.

Salimi S, Ghanbarpour MR, Solaimani K, Ahmadi MZ (2008). Floodplain mapping using hydraulic simulation model in GIS. J. Appl. Sci. 8(4):660-665.

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Catchment dynamics and its impact on runoff generation: Coupling watershed modelling and statistical analysis to detect catchment responses

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Catchment response as consequence of changes in vegetation cover and land use management could not be well explained by statistical methods alone. At the same time, long range periodic and trend components of time series are not adequately predicted by watershed modeling. Therefore, joint application of statistical time series analysis and watershed modeling better help to understand the underlying climate variability and catchment dynamics. In this paper, an attempt has been made to examine the effects of climate variability and catchment dynamics at two agricultural watersheds situated in Rift Valley lakes basin of Ethiopia. Distributed hydrologic modeling is used to characterize catchment dynamics whereas statistical methods (time-trend, double mass curve, flow duration curve analysis) are applied to explain the accompanying climate variability. The simulated surface runoff component increased progressively since 1970s. Percentage annual surface runoff varies from 10 to 23% at Bilate, and 16% to over twofold at Hare watersheds. Statistical time-trend analysis reveals that annual streamflow do not show significant monotonic trend, whereas, extreme daily streamflow at Alaba Kulito of Bilate catchment is characterized by increasing trend during the analysis period. Recurrent yet statistically weaker change point years are found and are independent of each other in two watersheds and hence they are governed by land use attributes unique to respective watersheds that influence overland flow. A rising slope of rainfall-runoff double mass curve during post-1992 and 1994 period at Bilate and Hare watersheds respectively supports increasing trend of streamflow that is not fully explained by time-trend analysis. Time-segmented FDCs of monthly streamflow at Bilate shows increased quantile estimates of high flows for similar level of exceedance probability for recent years. The resulting runoff variability over the analysis period is attributed to climate variability and altered land use/cover conditions, the latter being dominant in the watersheds.

Key words: Land use dynamics, runoff, watershed modeling, trend analysis, climate change.

INTRODUCTION

The response of a catchment, that is, the runoff process is time and space variant and influenced by anthropogenic and climatic factors. For example, a drop of water falling in the form of precipitation usually traverses long path until it reaches the main stream. This long journey is accelerated or decelerated by land cover, soil, rainfall intensity and catchment geomorphologic parameters (Tiwari et al., 2006). The ever-increasing

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need for food, fiber and shelter coupled with growing national economic interests has aggravated the land use/land cover condition far greater than that of the natural processes. It is estimated that anthropogenic induced land use/land cover changes have transformed one-third to one-fourth of ice-free surface of our planet into other forms (Vitousek, 1994; Vitousek et al., 1997).

In most parts of the globe, significant areas of pristine ecosystems with lush vegetation have been converted to other forms of land use practices. Conversion of forest cover and dense naturally vegetated area to arable land (Angelsen, 1999; Barbier, 2004) and cattle grazing field has modified bulk water yield from the watersheds. Land use change has been strongest in tropical regions and its contribution to global runoff outweighs that of climate change (Piao et al., 2007). The world's largest natural tropical rain forest of Amazon is currently experiencing a large-scale deforestation due to increasing number of cattle herds in the region that ultimately requires substantial pasturelands (Chaves et al., 2008).

The ever growing demand for food crops, eventually emerging market for commercial crops, timbering and local energy consumption largely transformed the natural forest cover over Ethiopia. The 1985 official document of Ethiopian Relief and Rehabilitation Commission asserts that the country's forest cover was 44% in 1885, 16% in 1950 and 4% in 1985 (McCann, 1997).

The Rift valley lakes basin is one that had undergone similar level of forest decline over the last century. Dense forest and riparian woodlands of the Rift Valley lakes basin eventually converted to open woodland and rangelands. Major fraction of riparian forest that covers in the fertile delta region underwent clear cutting for cultivation.

The scientific understanding of the influence of forest cover and land use changes on water yield of the basin dates back to the early 20th century during which advanced computational power to handle spatial data was almost none-existent. In 1911, the Wagon Wheel Gap experimental watershed in central Colorado and the Priest River experimental forest in northern Idaho of USA were established to study forest associated influences on streamflow and erosion. Similar attempts were further extended to Europe (Hegg et al., 2006), Southern and Eastern parts of Africa (Wight, 1940; 1943; Dagg and Blackie, 1965) during later years. Field experiments and catchment studies conducted in multiple watersheds across the globe showed that forest reduction increases water yield (Hibbert, 1967; Edwards and Blackie, 1981; Bosch and Hewlett, 1982; Fohrer et al., 2001; Hundecha and Bardossy, 2004; Yu et al., 2008) and sediment load (Alansi et al., 2009) from the catchment.

Effect of land use/land cover on runoff and sediment yield from the catchment is investigated following different approaches worldwide. The classical hydrologic models of a pair catchment consideration such as control and treatments (Bates, 1921; Bates and Henry, 1928; Nemec et al., 1967) are in vogue to simulate the effect of land cover on watersheds. However, the areal extent of a control watershed is usually very small (Troendle and King, 1987; Hessling, 1999; Iroume et al., 2005; Hegg et al., 2006) and hence the physical relationship developed between paired catchments is usually influenced by the watershed geo-morphological parameters.

Mati et al. (2008) investigated the response of land cover changes at Mara Basin of Eastern Africa and observed significant increase in runoff over less than a couple of decades. Forest cover was reduced by approximately 70% over the years 1971 to 2000 in the Upper Gilgel Abbay catchment of the Blue Nile basin of Ethiopia (Rientjes et al., 2011). Reduced forest cover induced contrastingly variable streamflow trend in two neighbouring catchments of Blue Nile basin. Increased deforestation and intensified cultivation due to burgeoning population accelerated soil degradation rate and increased surface runoff at Ethiopian highlands (Hurni et al., 2005).

Study of catchment response with respect to vegetation cover and land use management are documented in many studies (Dunford and Fletcher, 1947; Bari and Smettem, 2004; Shi et al., 2007; Syvitski et al., 2007; Yang and Tian, 2009; Li et al., 2010; Seibert and McDonnell, 2010; Greenwood et al., 2011). Streamflow variability analyses in literature rely on independent treatment of statistical time series analysis and watershed modelling. However, urban and rural watersheds are under temporally varying vegetation cover condition and hence time series models alone cannot capture runoff variability as a consequence of diminishing or expanding plantation.

Refsgaard et al. (1989) provides a comprehensive guide to distinguish between man-induced influences and natural climate variability on hydrological regimes of catchments. It is suggested that joint application of statistical tests and watershed modelling approach would help to detect the prevailing variability in the catchment. Even though the scientific merits of the methods suggested by Refsgaard et al. (1989) are appealing, studies reported based on similar notions are scanty (Lorup et al., 1998; Li et al., 2012). Couples of studies attempted to explore the impacts of altered land use/land cover condition on hydrological regimes of Ethiopian watersheds using hydrological models (Zeleke and Hurni, 2001; Legesse et al., 2003; Gebresamuel et al., 2010).

Computational advancements coupled with availability of satellite data to extract valuable spatial information provide an aura of confidence to analyze watershed hydrologic processes better; however, limited spatial and temporal datasets available to characterize the watershed processes besetting the endeavor of scientific communities in the developing countries. The Rift Valley lakes basin of Ethiopia is one among which access to real-time hydro-meteorological data and spatial information is scarce. It is a basin characterized by very limited historical hydro-climatic records and remains under significant water and land resources exploitation for the benefit of the rural population.

The present study concentrates on examining the response of a catchment to runoff for temporally varied land use/land cover conditions using physically based distributed hydrologic modelling. The catchment response is investigated by simulating runoff for temporally varied land use/land cover conditions over the last quarter of twentieth century. Finally, statistical analysis (trends, double mass curve and flow duration curves) of observed streamflow and rainfall is carried out to investigate the behavior of associated time-trend with respect to the prevailing land use/land cover conditions.

Description of the study area

The impact of land use dynamics was investigated in two rural watersheds (Bilate and Hare) in the Rift Valley lakes basin of Ethiopia. The watersheds are selected on the basis of multiple considerations. Prevailing land use dynamics over the last couple of decades and sedimentation of conveyance channels resulted in major anthropogenic disturbances in the watersheds. The highland portions of the watersheds are characterized by humid climatic condition whereas the lower flood plains are known for their semi-arid nature. Increased surface water resource competition for agricultural purpose is eminent in semi-arid parts of the watersheds.

Bilate watershed (5330 km^2 at the gauging outlet) is characterized by humid and semi-arid climatic conditions with bimodal rainfall pattern with major rainfall during the summer monsoon season. The average annual rainfall variability is linearly correlated to the altitude in the watershed. Deforestation due to expansion of agricultural lands, cattle grazing and timbering substantially reduced the vegetation cover in the watershed. Deep gullies and massive bare soil pillars at upstream part of the watershed testifies its vulnerability to erosion hazard. The entire watershed practices a mixed cropping pattern where the lower foot of the watershed utilizes irrigation (approximately 1260 ha of government owned farm) to grow commercial crops such as tobacco and maize. Currently the demand for irrigation water is increasing and small scale communal and medium scale private investors are under urgent course of water demand.

Hare watershed (166.5 km^2 at the gauging outlet) is characterized by steep valleys at upstream mountainous highland and progressively stretches to flat fluvial plain until it joins the terminal lake Abaya. The lower plain area of the watershed is known for its intense competition for irrigation water among the local farmers, state and private owned irrigation firms. The upstream highland region of the watershed experiences a humid climate with an average annual rainfall magnitude of 1250 mm in contrast to 870 mm of rainfall at Arba Minch region of the downstream sub-watershed area. The upstream community of Hare basin is fully engaged on rain-fed cultivation and associated agricultural activities. The lower fluvial plains utilize communal based traditional and modern irrigation schemes to supplement rain-fed cultivation on nearly 2200 ha of land. Maize, sweet potato, banana, mango and cotton are among the major crops growing in the semi-arid irrigated watershed territory. Land resource competition as a result of growing number of population aggravated conversion of forest cover into agricultural plots and residential area. Household energy consumption is almost entirely based on wood biomass in the watershed and becomes another culprit to forest reduction. Figure 1 presents the major river basins in Ethiopia and location of study watersheds (Bilate and Hare).

MATERIALS AND METHODS

Data sources

The datasets utilized to investigate the impact of land use/land cover changes on runoff generation at agricultural watersheds include time variant landsat imageries, DEMs, soil and hydro-meteorological dataset. Table 1 provides details of orthorectified four band Multi-Spectral Scanner (MSS) LandSat-4, Thematic Mapper (TM) and seven band Enhanced Thematic Mapper Plus (ETM+) land cover imageries acquired from Global Land Cover Facility archives (http://glcf.umiacs.umd.edu/data/landsat) for the present study.

An enhanced 90 m x 90 m longitudinal resolution processed Shuttle Radar Topographic Mission DEM data version 4.1 (Jarvis et al., 2008) is accessed from International Centre for Tropical Agriculture (CIAT) online source (http://srtm.csi.cgiar.org) and processed using ERDAS Imagine 9.3 following unsupervised image classification. Soil feature classes and respective physical properties for the study watersheds are customized from World Food and Agricultural Organization (FAO) soil map. Required weather data to run hydrologic model has been gathered from regional and national meteorological offices. Daily rainfall, maximum and minimum temperature, wind speed, sun shine hours and relative humidity for five nearby stations for a record length between 1980 and 2009 are collected for subsequent analysis. Table 2 describes details of weather input data available for analysis. Daily streamflow records are collected from Ministry of Water Resources (MoWR) hydrological data archives of Ethiopia. Standard preliminary data analysis for consistency is conducted.

Land use/Land cover data

Temporal landsat images (1973/76, 1984/86 and 2000) acquired from Global Land Cover Facility archives have been processed to extract required land use information. The selected temporal landsat images are sufficiently long enough to each other to observe the expected land use changes and consequent catchment responses. Geometrically corrected landsat images are processed using ERDAS Imagine image analysis facilities. Supervised and unsupervised image classification is applied and further assimilated based on land use class similarity. Classified land use map units are also verified against coarser resolution land use maps developed by the Ministry of Water Resources (MoWR) of Ethiopia. The present classification is based on small spatial scale and hence identified more land use classes than the existing broad classification by MoWR. The land use management classes for the

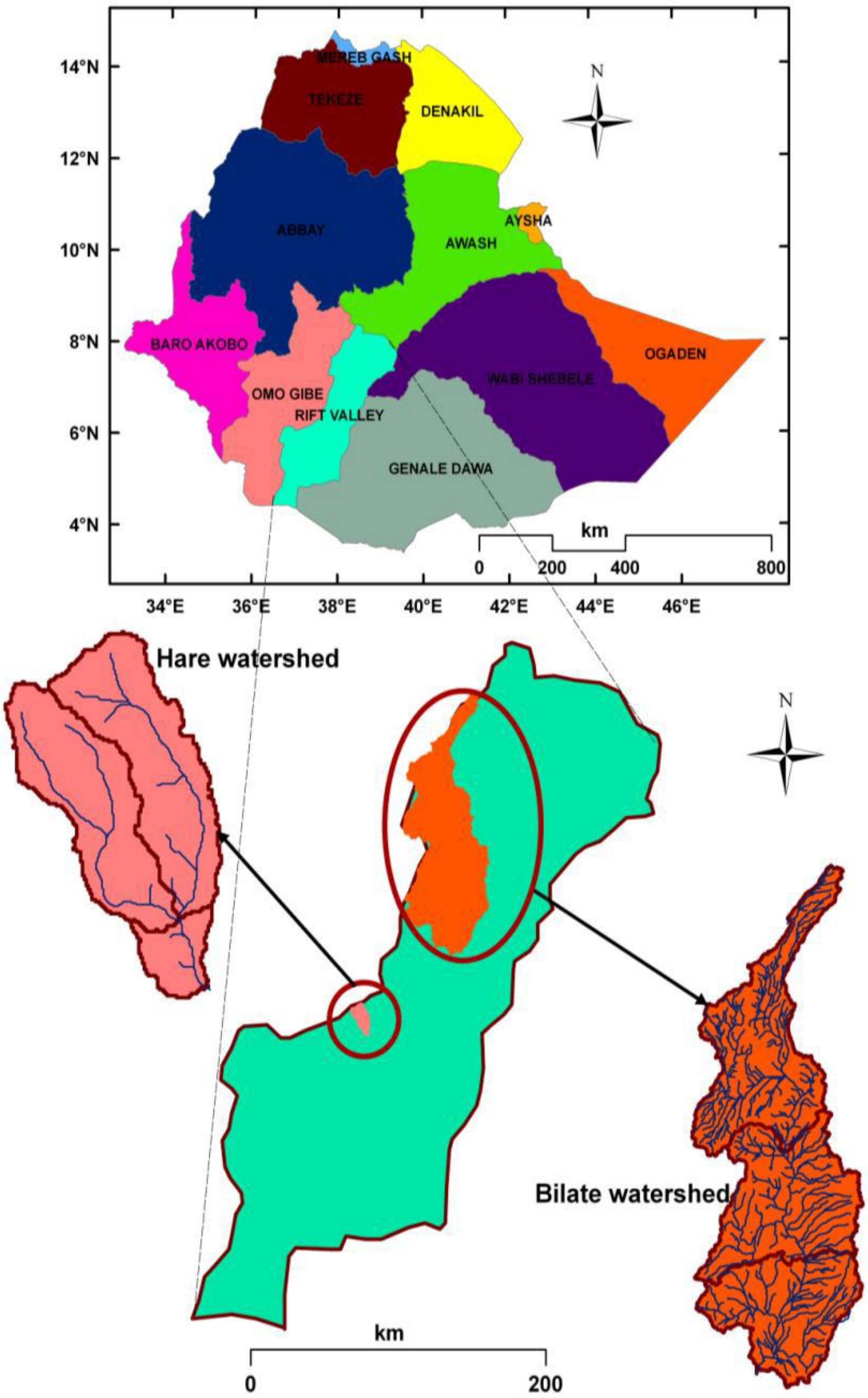

Figure 1. Description of the study area: The figure shows major river basins in Ethiopia (top) and the two study watersheds in the Main Rift Valley lakes basin of Ethiopia (bottom).

Table 1. Orthorectified landsat images used for land use/land cover classification.

Landsat image ID	Sensor type	Date acquired	Path/Row	Producer	Watershed associated
029-736	MSS	Jan. 31, 1973	181/055	Earthsat	Bilate
044-075	MSS	Jan. 25, 1976	181/056	Earthsat	Hare
012-383	TM	Nov. 22, 1984	169/055	Earthsat	Bilate
012-382	TM	Nov. 22, 1984	169/054	Earthsat	Bilate
012-371	TM	Jan. 21, 1986	168/055	Earthsat	Bilate
012-384	TM	Jan. 28, 1986	169/056	Earthsat	Hare
037-658	ETM+	Nov. 26, 2000	169/055	Earthsat	Bilate
037-883	ETM+	Feb. 05, 2000	168/055	Earthsat	Bilate
037-659	ETM+	Jan. 27, 2000	169/056	Earthsat	Hare

Table 2. Details of hydro-meteorological dataset used for analysis.

Hydro-meteorological data/stations	Alaba Kulito	Hawassa	Bilate Farm	Arba Minch Farm	Chencha
Daily weather data					
Rainfall	√	√	√	√	√
Max. and Min. Temperature	√	√	√	√	√
Wind Speed	√	√		√	
Sunshine Hours	√	√		√	
Relative humidity	√	√		√	
Record Length	1980-2009	1980-2009	1980-2009	1980-2009	1970-2006
Daily streamflow					
Bilate at Alaba Kulito (1971-2006)	√			√	
Hare near Arba Minch (1980-2006)					

study area are defined following Anderson et al. (2001) land use/land cover classifications described herein under.

Agricultural lands: These include diverse class of cultivated land, plots covered by food and commercial crops (croplands) and land units covered by residuals after immediate harvest.

Forest lands: Forest lands have usually tree-crown areal density capable of modulating the micro climate and water holding capacity of watershed. They range from densely populated tall trees of tropical rain forest used for timbering to moderately grown green forest. Forest lands could be evergreen, deciduous or mixed forest land.

Woodlands: Woodland is a low-density forest forming open habitats for wildlife with limited sun shade. Under drier weather condition and early stage of forest succession, woodlands may convert into Shrublands.

Shrublands: Shrublands are a plant community characterized by vegetation dominated by shrubs, often also including grasses, herbs, and geophytes.

Range lands: These land cover units are typical to arid and semi-arid lands characterized by xerophytic vegetation and transition zones from forest land to sparse woodlands.

Grass lands: These are land units where the potential natural vegetation is predominantly grasses and grass-like plants. It is dominated by naturally occurring grasses as well as those areas of actual rangeland that have been modified to include grasses.

Water and marshy land: Area that remains water logged and swampy throughout the year, and rivers.

Pasture land: Pastureland is an area covered with grass or other plants suitable for the grazing of livestock.

Barren land: Land of limited ability to support life and in which less than one-third of the area has vegetation or other cover. It is an area of thin soil, sand or rocks and the areal coverage of available vegetation is much less than that of range land.

The major land use/land cover units identified for the study watersheds are forest land, woodland, shrub land, pasture, green vegetation, agricultural land, settlements and water body.

Watershed modelling under changing land use/land cover conditions

Physically based distributed hydrologic models such as Syst`eme Hydrologique Europ´een (SHE) (Abbott et al., 1986), Institute of Hydrology Distributed Model (IHDM) (Beven et al., 1987) and SWAT model (Arnold et al., 1993; 1998) have the ability to synthesize various spatial information and weather data to predict catchment responses. SWAT model (Arnold et al., 1993; 1998) has got growing demand among watershed modelers due to its capability to model the watershed responses at very small spatial scale characterized by unique land use, soil and slope attributes called hydrologic response units (HRUs). It is a process oriented hydrologic model developed to predict the impact of land use management practices on water, sediment, agricultural chemical yields from large and complex watersheds with varying degree of spatial information over long period of time.

In the present study, SWAT model is used to analyze the impact of change in land use/land cover on runoff generation in study basins. The ArcHydro module of the ArcSWAT model delineates the watershed boundary and generates prevailing stream network from available digital elevation model with assigned draining area threshold magnitude. The smaller the draining area threshold the denser the stream network. This helps capture the spatial variability of a channel network at very small areal extent. Runoff is generated from individual HRUs and routed to form the main channel flow. The overland flow velocity is affected by the prevailing land cover and soil properties. As a consequence of which both overland and channel flow travel time is affected and subsequent runoff accentuation or attenuation occurs.

Land use/land cover information separated by moderately sufficient time periods (1976/1986/2000) are used as input dataset to the watershed modeling. Other spatial input parameters such as soil, slope and weather information are organized to suit SWAT modeling. Runoff simulation in the watersheds is carried out on daily basis. The model is calibrated using the year 2000 land use/land cover information for both watersheds. The model parameters are further utilized to simulate runoff at desired temporal and spatial scale for the years 1976 and 1986. In SWAT model, the bulk simulated water yield is comprised of surface runoff (SUR Q), lateral flow (LAT Q) and groundwater flow (GW Q). The model has the capability to separate each component independently so that the relative response of catchment to individual components can easily be evaluated. Catchment morphometric parameters and spatial variables such as soil and land covers affect the partition of liquid mass flow into the corresponding components. The study attempts to examine how the land use/land cover has either enhanced or retarded the quick surface flow component being all other factors held constant. Runoff has been simulated for three different land use/Land cover conditions in the watersheds outlet and subsequently analyzed.

Land use/Land cover change and streamflow trend

To reinforce the justification from watershed modeling, the behavior of observed streamflow and rainfall in the study watersheds is examined. Detection of monotonic trends and abrupt changes are assessed using statistical trend analysis and rainfall-runoff double mass curve analysis. The behaviour of historical streamflow is further examined from flow duration curve analysis for time-segmented series.

Monotonic and step changes in annual and daily extreme streamflow magnitude are examined applying the commonly used Mann-Kenadill (MK) (Mann, 1945; Kendall, 1955) and Mann-Whiteny-Pettitt's (MWP) (Pettitt, 1979; Zhang and Lu, 2006) change detection approaches. The MK test statistic is broadly explained in many literatures and hence a concise statistical background of MWP is presented here.

The MWP change detection method is a non-parametric test that can be used to analyze data from two independent groups when measurement is ordinal. It analyzes the degree of separation or overlap between the two groups. For a sequence of random variables X_1, X_2, …, X_T which have a change point at τ (X_t) for t = 1,2,…, τ have a common distribution function F1(x) and X_t for t= τ +1, … T have a common distribution function F2(x) where F1(x) ≠ F2(x) (Pettitt, 1979). The null hypothesis (Ho) assumes that the two set of scores are samples from the same population (no change) and the alternative hypothesis (H1) is that the two sets of scores differ systematically (there is change).

The test statistic is:

$$K_T = \max_{1\le t\le T} \left|U_{t,T}\right| \quad = \quad \max\left(K_T^{+}, K_T^{-}\right) \tag{1}$$

where $$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}\left(X_i - X_j\right) \tag{2}$$

and $$\operatorname{sgn}(\theta) = \begin{cases} 1 & \text{if} \quad \theta > 0 \\ 0 & \text{if} \quad \theta = 0 \\ -1 & \text{if} \quad \theta < 0 \end{cases} \tag{3}$$

For changes in one direction, that is, for downward (K_T^+) or upward shift (K_T^-), K_T is given as:

$$K_T^{+} = \max_{1\le t\le T} U_{t,T} \quad \text{and} \quad K_T^{-} = -\min_{1\le t\le T} U_{t,T} \tag{4}$$

The significance level associated to K_T is estimated by:

$$\rho = \exp\left(\frac{-6K_T^{2}}{T^3 + T^2}\right) \tag{5}$$

If the magnitude of ρ is smaller than the specific significance level (for example α =0.05) the null hypothesis is rejected. The time t when K_T occurs is the change point time.

RESULTS AND DISCUSSION

Land use/Land cover dynamics in the study watersheds during 1973 to 2000

Temporal land use/land cover map developed from satellite imageries for three different time spans (1973/76, 1986 and 2000) shows major transformation of land cover and land use management over the last quarter of twentieth century.

A phenomenal increase in cultivated land and settlement area over the analysis period is observed at both watersheds. Forest cover decreased by 34.5 and 50.7% during 1976/86 and 1986/2000 time period respectively at Bilate watershed (Figure 2). The total area covered by cultivated land, settlement area and barren land increased by 30.9 and 23.4% for 1976/86 and 1986/2000 land use condition respectively. However, on aggregate the rangelands increased by 26.7% whereas the pasture land units decreased by 43.8%. The decrease in pasture land might be the result of growing demand of arable land for crop cultivation in most parts of the watershed. Land units that lost its fertile top soil formation due to excessive erosion and weathering activities are commonly located as small patches in the middle and lower Bilate basin.

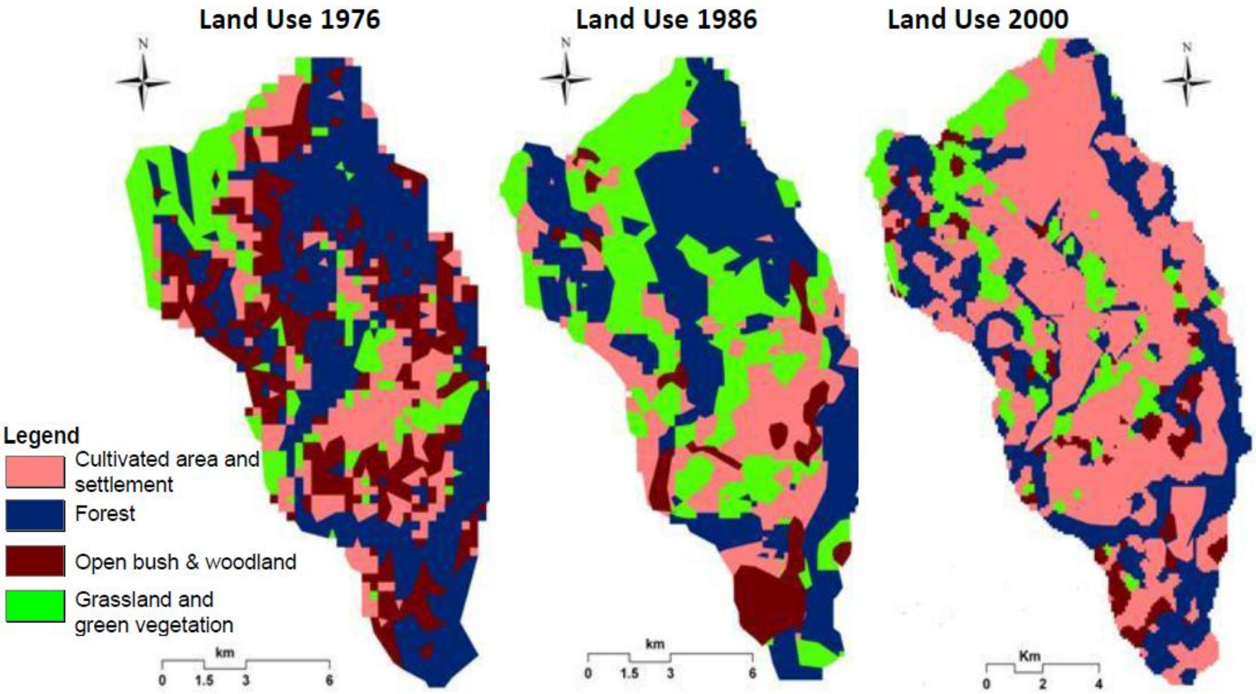

Figure 2. Reclassified land use/land cover classes for use in hydrologic modeling at Hare watershed.

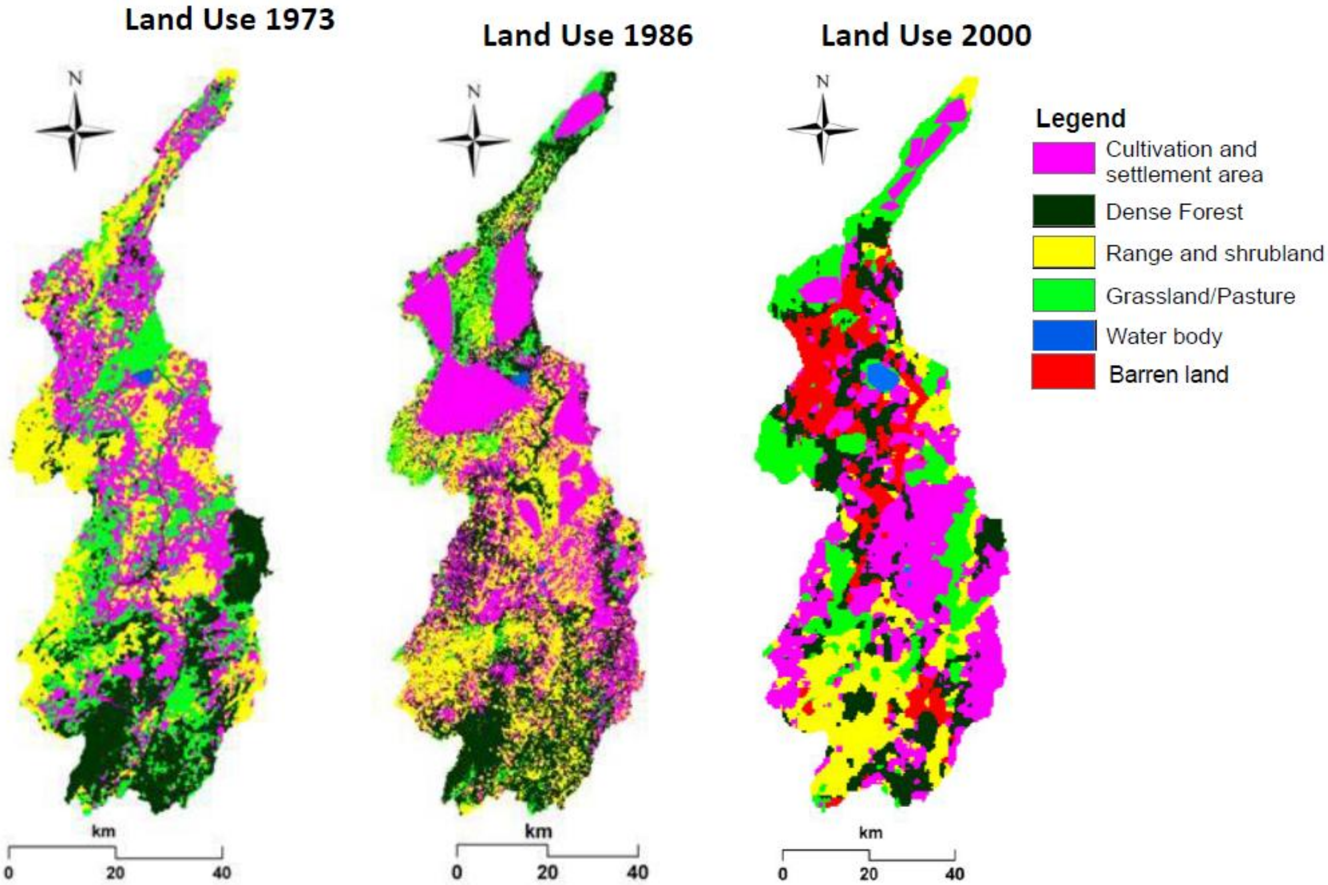

Figure 3. Reclassified land use/land cover classes for use in hydrologic modeling at Bilate watershed.

Table 3. Areal coverage of reclassified land use /land cover condition for study watersheds.

Land use/Land cover class	Percentage Land use/Land cover			Percentage change		
	1976	1986	2000	1976-1986	1986-2000	1976-2000
Bilate Watershed						
Cultivation and Settlement	36.1	47.2	58.3	30.9	23.4	61.6
Forest-mixed	26.5	17.4	8.6	-34.5	-50.7	-67.7
Range and shrubland	17.2	24.8	21.8	44.0	-12.0	26.7
Pasture	20.2	10.6	11.4	-47.4	6.7	-43.8
Hare watershed						
Cultivation and Settlement	29.6	36.4	47.4	22.7	30.3	59.9
Forest-mixed	30.2	25.3	18.2	-16.2	-28.1	-39.8
Rangeland	24.3	27.2	24.2	12.1	-11.0	-0.2
Pasture	15.9	11.1	10.2	-30.0	-8.1	-35.7

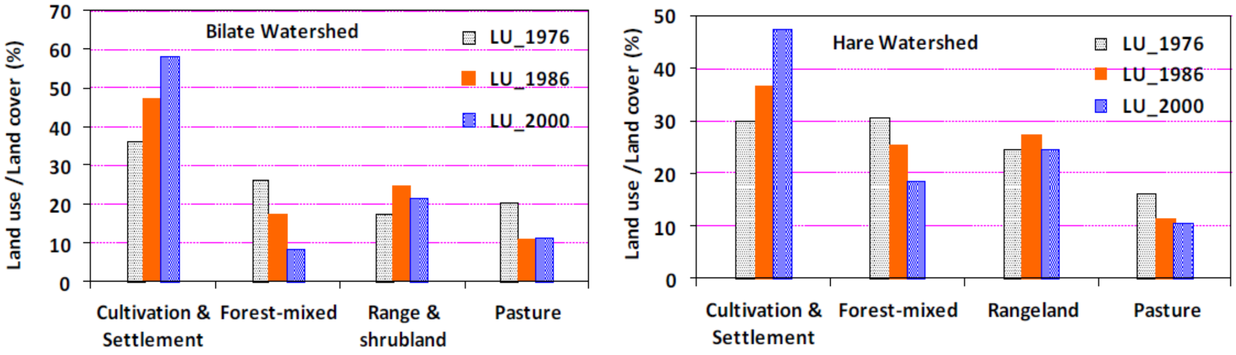

Figure 4. Temporal variations of dominant land use/land cover proportion in the study watersheds.

The land use/land cover condition at Hare basin follows similar temporal trend to that of Bilate basin. An aggregate increment of 60% in cultivated land and rural settlement whereas 40% decrement in forest cover is identified during 1976 to 2000 analysis period (Figure 3). Area under pasture and rangeland found to decrease during the same period. Table 3 provides major land use /land cover conditions and respective percentage changes over the time period 1976/1986/2000 at Bilate and Hare watersheds of the Rift Valley lakes basin of Ethiopia. The major fraction of land use/land cover is occupied by cultivation, settlement and forest cover during 1970s, however, the forest cover eventually reduced during the last two decades of twentieth century (Figure 4). The upstream riverine course of Hare watershed commonly grows an evergreen bamboo plantation. Its dense and fibrous roots have soil gripping capability hence minimizes erosion of top soil layers.

Land use/Land cover dynamics and hydrologic modeling

Land use/land cover affects runoff in the form of accelerated or retarded overland flow as a result of slow or fast infiltration rate and initial abstraction due to canopy cover (Jinno et al., 2009). The surface runoff component is separated from the total water yield of a catchment to assess its variability due to altered land use/land cover conditions. The impact of temporally varying land use/land cover condition on runoff generation in the watersheds is modeled using Soil and Water Assessment Tool.

Hydrologic modelling

The Soil and Water Assessment Tool is data intensive model that captures the underlying hydrologic processes at small spatial scale with unique soil, land use and slope attributes. DEM, soil, land use, weather and an optional stream outlets location data are required for initial model setup. The slope map of the watersheds is reclassified into three slope classes (0 to 5%, 5 to 10% and >10%) based on the topography of the watersheds. Feature class soil maps and corresponding soil physical properties are extracted from FAO soil map for dominant soil units. Local soil information organized from *in-situ* observations are further used to augment the soil classification. The soil units are categorized into 9 and 4 dominant soil classes at Bilate and Hare watersheds respectively. Land use/land cover information is extracted from Satellite imageries for three different time period are described in the findings of this research used for SWAT model run. Model sensitivity analysis is carried out for both with and without observed discharge cases to identify the most sensitive model parameters. SWAT model is calibrated for the year 2000 land use condition and subsequently used to predict runoff for 1976 and 1986 land use conditions. The Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm (Abbaspour, 2009) is applied for model calibration. Model calibration and validation is covered widely in previous works for the study watersheds. Other input variables such as weather, soil and catchment morphologic parameters remain constant for each simulation. This enables us to identify the catchment response uniquely to land use changes.

SWAT model disaggregates the output into surface runoff component, lateral flow and shallow aquifer flow. The response of a catchment as a result of land use change is evaluated in terms of simulated surface runoff component. It is observed that the surface runoff component increases progressively since mid 1970s at both watersheds. The rate of change of runoff with respect to the base period (1976) is more significant during wet years. This is due to high intensity and extended duration of rainfall events that are more likely to produce runoff immediately with minimal travel time. Moreover, availability of sufficient antecedent moisture condition in the soil retards infiltration rate and accelerates overland flow.

Catchment geomorphologic factors also attributed to varying rate of change of surface runoff magnitude. In steep and smaller size Hare watershed the rate of change is more profound. This is because, the diminishing rate of vegetation cover over the analysis period aggravated runoff generation in Hare watershed. The catchment response is more significant during wet years of the analysis period. The land use condition in the year 2000 increased annual surface runoff by 10 to 23% at Bilate watershed with respect to 1976 reference line. The rate of change is higher at smaller size Hare watershed. The increment extends from 16% to more than 100% during the very wet years. Figure 5 presents the relative proportion of simulated surface runoff component for three different land use conditions at two watersheds maintaining all other factors constant throughout the three simulations.

Average monthly predicted surface runoff is compared against respective rainfall in the watersheds during the analysis period. The surface runoff component shows better agreement to corresponding rainfall for all simulations. The coefficient of determination (R^2) ranges from 0.85 to 0.96. A better correlation ($R^2 = 0.91$-0.96) is observed at Hare watershed where the statistical relationship follows an exponential law (Figure 6). Intercomparison of simulated annual surface runoff to corresponding annual rainfall clearly shows increasing runoff magnitude since 1976 land use condition at both watersheds. Simulations for specific land use conditions are approximated by a lower order polynomial and exponential curves where simulated runoff values for recent land use conditions are modestly lying above the early ones (Figure 7). This indicates the recent land use condition is able to generate higher runoff magnitudes than the past years.

Summer monsoon season rainfall dominates at Bilate watershed and subsequently yielded substantial amount of total water yield during June-October months whereas, bimodal rainfall pattern at Hare watershed produced alternating raised hydrograph limbs during the rainy seasons. The major rainfall season at Hare extends from mid of March to the first decade of June and produced higher peaks during April-May heavy rainfall. The average monthly total runoff was found to increase since the 1976 land use condition. During the dry months the variability in simulated total runoff is insignificant (Figure 8).

Streamflow trend analysis

Statistical trend analysis to detect possible monotonic trends and step changes is conducted for annual and extreme daily streamflow events at Bilate (1971 to 2005) and Hare (1970 to 2007) watersheds. We further examined the historical variability of observed streamflow at Alaba Kulito using flow duration curve (FDC). Mann-Kendall (MK) trend analysis is conducted both for original and prewhitened series to account for the effect of significant serial correlation while detecting possible trends. MK-trend analysis for original and prewhitened series reveals that annual streamflow shows insignificant monotonic trend at both watersheds. However, daily extreme (daily maximum and minimum) streamflow events at Bilate basin are characterized by increasing trends at 5% significance level. No statistically significant streamflow trend is detected at Hare watershed for annual and extreme daily events. The prewhitened series of daily minimum streamflow of Hare is characterized by increasing trend at 10% significance level (Table 4).

Mann-Whitney-Pettitti's method employed for step change detection shows couple of statistically weaker change points at both watersheds. The years 1999 and 1992 are estimated to be with statistically significant yet weak change points at Bilate basin whereas the years 1990 and 1986 are detected as possible change points at Hare watershed. The change points detected at two neighbouring watersheds show that the magnitude and temporal location of change points vary slightly. The change points are noticeable in the mid of 1980s and 1990s. These change points are associated to low annual

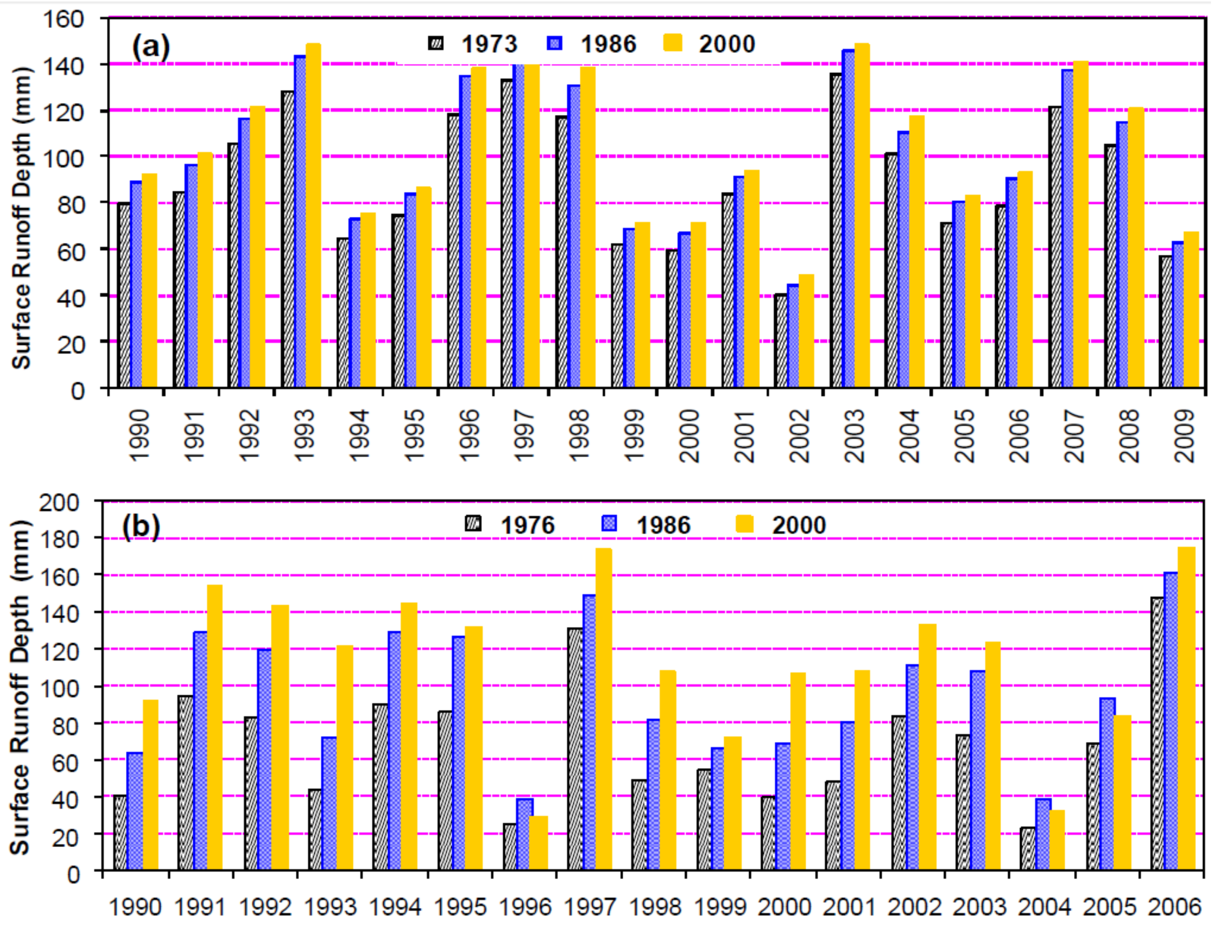

Figure 5. Simulated surface runoff component for different land use/land cover condition during the analysis period.

rainfall years. Minor seasonal water abstraction and other unspecified catchment condition that are not quantified in the present context might have attributed to this recurrent and statistically weak change points. The observed land use changes in the watersheds are not dramatic but they have been developed gradually over the years.

Cumulative mass analysis of rainfall and runoff provides statistical information regarding the underlying input-output relationship. When there is no significant alteration in rainfall and runoff pattern due to various circumstances, the data points in the double mass curve fit into a straight line with uniform slope. However, sudden break in slope line of the mass curve is eminent when either or both of the variables undergo localized or long term deviations from the preceding values.

Double mass curve analysis of observed annual streamflow and rainfall conducted in the study watershed shows slight deviation in slope line of the double mass curve around the year 1992 and 1994 at Bilate and Hare watersheds respectively (Figure 9). This shows that changes occurred in land use/cover condition in the two watersheds are independent. Even though the change in slope after the break point is small (0.005 MCM/mm at Bilate and 0.012 MCM/mm at Hare watersheds), yet it is indicative of increased runoff after 1990s.

Contrary to insignificant trends of annual rainfall in the study watersheds, the maximum daily streamflow at Alaba Kulito of Bilate basin follows statistically increasing trend since 1980. However, average annual streamflow at both watersheds does not reveal statistically significant trends. Altered land use/cover condition enhanced quick storm responses with less attenuated hydrograph. The increasing trend of maximum daily streamflow at Bilate is a characteristic example of such less diffused streamflow in time and space.

The percentage of time a given flow magnitude equaled or exceeded an observation period, described as flow duration curve (FDC), explains the prevailing relationship between the magnitude and frequency of streamflow. The behavior of historical streamflow variability could be studied from the plot of discharge versus corresponding probability of exceedance. It should be noted that the underlying relationship is dependent up on the total record length (n-values) utilized for FDC construction. Average monthly streamflow records are divided into segments of preferably ten years and FDCs are

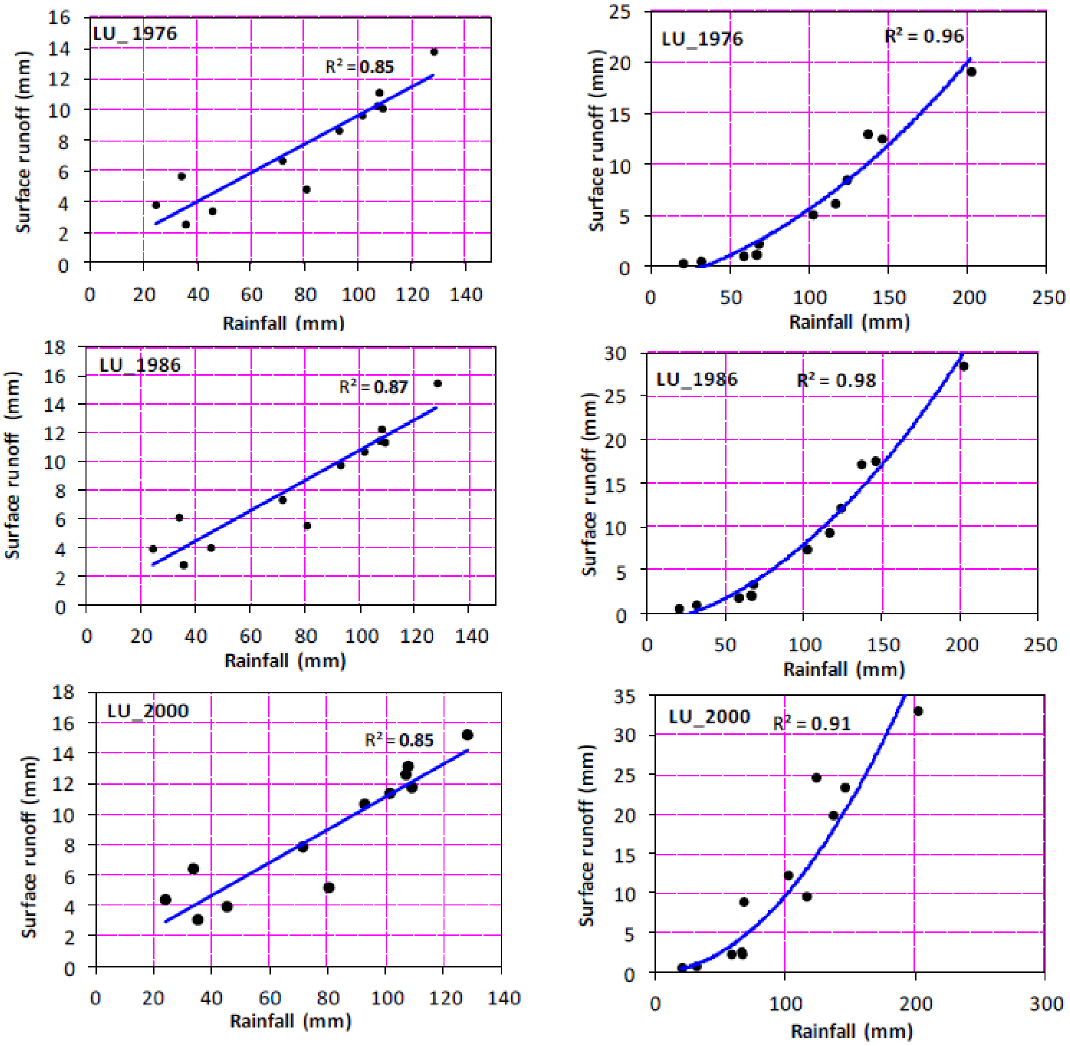

Figure 6. Average monthly simulated surface rainfall-runoff relationship for different land use condition at Hare (left column) and Bilate (right column) watersheds.

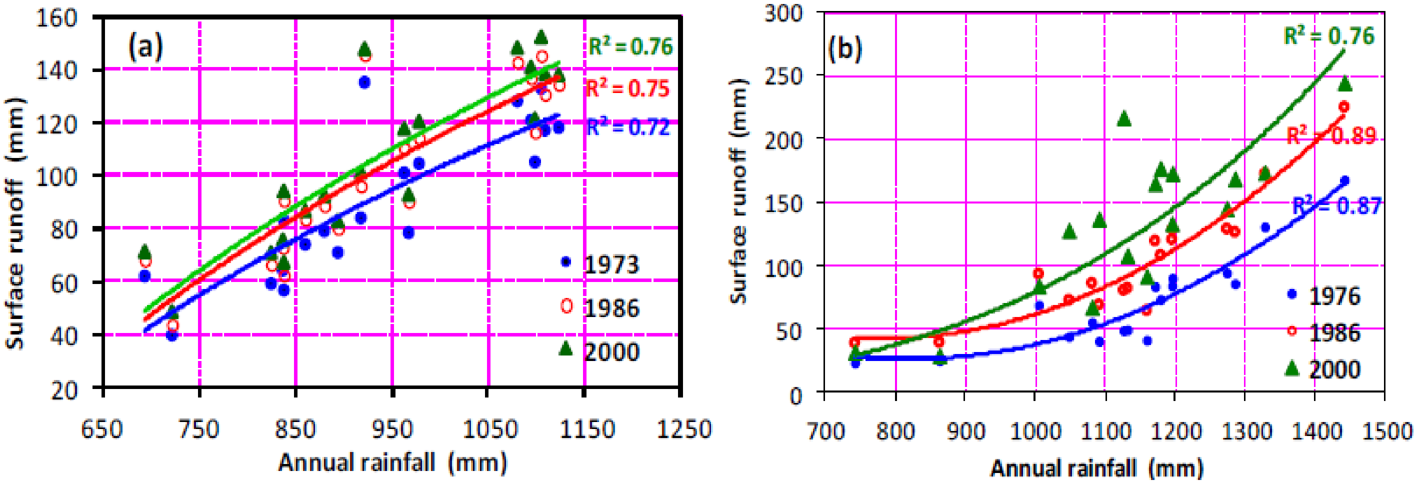

Figure 7. Average annual simulated surface runoff and rainfall relationship for three (1976, 1986 and 2000) land use/land cover conditions at Bilate (a) and Hare (b) watersheds. Smooth lines are polynomial (a) and exponential (b) curves fit to the data points. The best fit line lies atop the other for recent year's rainfall-runoff relationship.

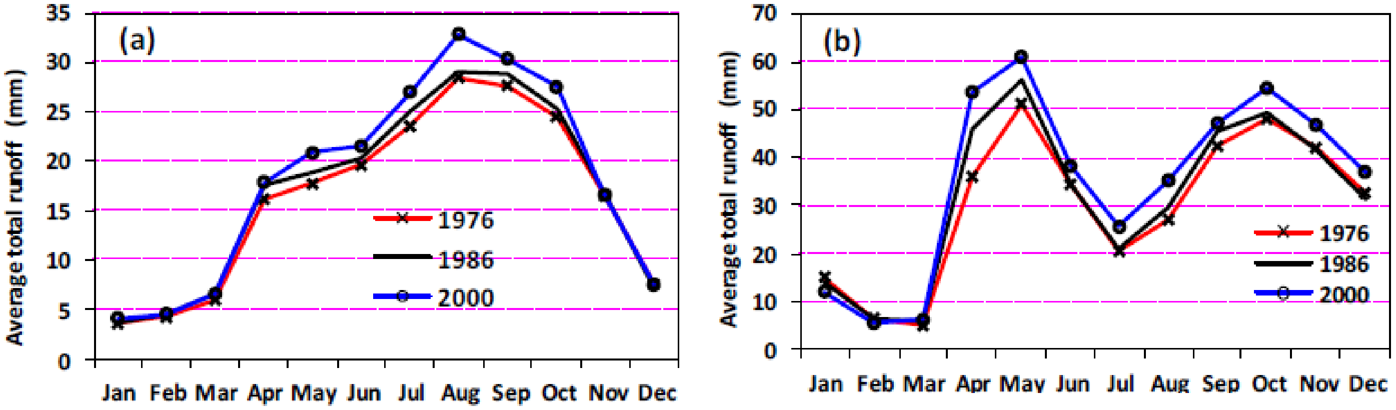

Figure 8. Simulated average monthly total water yield for three (1976, 1986, 2000) land use/land cover conditions at Bilate (a) and Hare (b) watersheds. The simulation is averaged for 1990-2009 at Bilate and 1990-2006 at Hare watersheds.

Table 4. Trend analysis of annual and extreme daily streamflow series for the study watersheds.

Streamflow series	Trend test statistics					
	Mann-Kendall original series			Mann-Kendall prewhitened series		
	S	Z	Trend	S	Z	Trend
Bilate Streamflow						
Annual series	49	0.676	NS	47	0.648	NS
Daily maximum series	186	**2.612**	+	227	**3.291**	+
Daily minimum series	197	**2.807**	+	213	**3.090**	+
Hare streamflow						
Annual series	27	0.536	NS	35	0.701	NS
Daily maximum series	-41	0.826	NS	-57	1.175	NS
Daily minimum series	68	1.398	NS	94	**1.943**	+

S= Mann-Kendall trend test statistic; Z= Standard normal variate; NS= No statistically significant trend; += Increasing trend; Critical Z-value is 1.96 and 1.645 at 5 and 10% confidence levels.

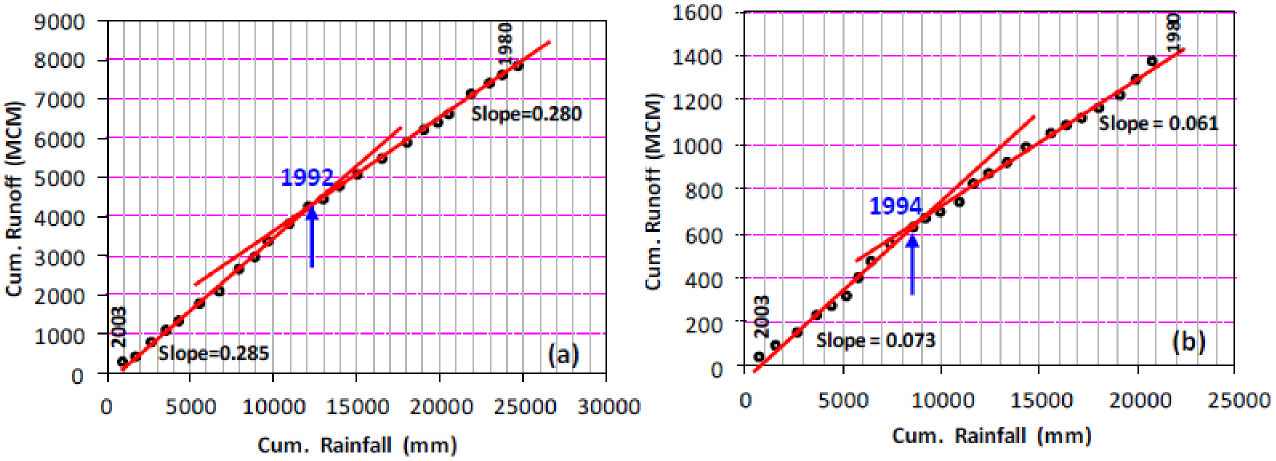

Figure 9. Double mass curve analysis of observed runoff and rainfall at Alba Kulito (a) and Hare-near Arba Minch (b). The slight break in slope of mass curve is observed around 1992 and 1994.

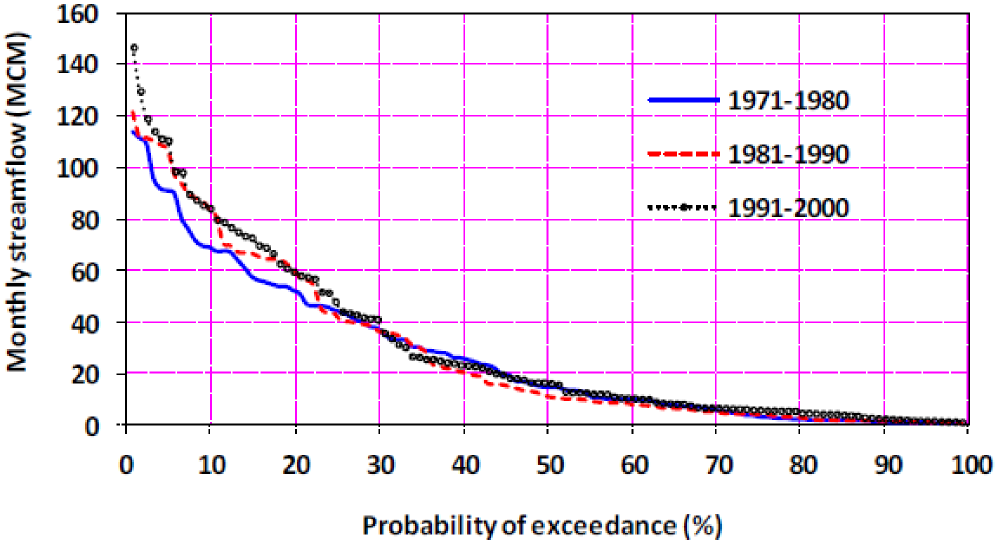

Figure 10. Flow Duration Curves (FDCs) for various segments of average monthly streamflow records of Bilate River at Alaba Kulito station. The FDC for recent decade is lying above the earlier one for the same probability of exceedance.

constructed for each segment. The intent of sub-segmented FDC is to study the relative variability in the behavior of streamflow over three decades; namely, 1970s, 1980s and 1990s. Our analysis of FDC is limited to Bilate streamflow with relatively long and uninterrupted flow records. The corresponding average monthly streamflow at Bilate in the 1990s are positioned at higher level than that of 1970s and 1980s for the same level of exceedance probability. The transition segment, that is, 1980s is characterized by slightly wiggling FDCs (higher quantile estimates during the high flow period and lower estimates during the low flow period) that lies between the 1970s and 1990s (Figure 10). The decadal variability in streamflow could be inferred from such short segmented FDCs which otherwise could not be captured from long term time-trend analysis.

Conclusions

The studied watersheds are under intensive catchment modification since the 1970s. Substantial fraction of riparian forest and pristine vegetation cover were converted to agricultural land and grazing field. Compared to its 1976 reference period, the percentage of forest cover declined by 68 and 40% at Bilate and Hare watersheds respectively. Meanwhile, the gross area of agricultural land, permanent settlements and barren land were collectively expanded by approximately 60% of its baseline proportion at both watersheds during the same period.

The response of a catchment as a result of changing land use/land cover condition is modeled using SWAT for three different (1976/1986/2000) temporal land use conditions. The SWAT model separates overland flow component from total catchment water yield. The simulated surface runoff component increases progressively since 1970s. Percentage annual surface runoff varies from 10 to 23% at Bilate, and 16% to over twofold at Hare watersheds. Statistical time-trend analysis reveals that annual streamflow do not show significant monotonic trend, however, extreme daily streamflow at Alaba Kulito of Bilate catchment is characterized by increasing trend during the analysis period. Recurrent yet statistically weaker step change points are observed in the years 1986, 1990, 1992 and 1999 in the watersheds. The change point years are independent of each other in two watersheds and hence they are governed by land use attributes unique to respective watersheds that influence overland flow. Slightly rising slope of rainfall-runoff double mass curve during post-1992 and 1994 period at Bilate and Hare watersheds respectively supports the subtle increasing trend of streamflow that is not fully explained by time-trend analysis. Time-segmented FDCs of monthly streamflow at Bilate shows increased quantile estimates of high flows for similar level of exceedance probability for recent years.

The attribution of land use/land cover to inter-annual streamflow variability is clearly demonstrated in the present analysis. The increasing trend of observed daily maximum flow at Alaba Kulito and slightly raised slope of rainfall-runoff double mass curve since 1992 supports the attribution of climate induced changes at Bilate catchment. There are an obfuscated time-trend responses for other variables such as average annual and daily minimum flow at both catchments, but not justified statistically. Annual rainfall time-trend analysis in the study watersheds is marked by statistically insignificant trends. This has been covered by previous studies of the authors. Therefore, joint application of statistical methods and watershed modeling has an advantage to distinguish the underlying variability between climate change and catchment dynamics. The effect of catchment dynamics is modeled by watershed model and accompanying long term climate variability, if any, is explained by statistical tests. This avoids the propensity to associate the resulting variability to either of the two (natural climate variability and land use changes).

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Abbaspour KC (2009). SAWT-CUP2 calibration and uncertainty program user manual version 2. Eawag: Swiss Federal Institute of Aquatic Science and Technology.

Abbott MB, Bathurst JC, Cunge JA, O'Connell PE, Rasmussen J (1986). An introduction to the European Hydrological System – Syst`eme Hydrologique Europ´een, "SHE", 2: History and philosophy of a physically-based, distributed modelling system, J. Hydrol. 87:45-59.

Alansi AW, Amin MSM, Halim GA, Shafri HZM, Thamer AM, Waleed ARM, Aimrun W, Ezrin MH (2009). The effect of development and land use change on rainfall-runoff and runoff-sediment relationships under humid tropical condition: Case study of Bernam watershed Malaysia. Eur. J. Sci. Res. 31(1):88-105.

Anderson JR, Hardy EE, Roach JT, Witmer RE (2001). A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper, 964, first printing, 1976.

Angelsen A (1999). Agricultural expansion and deforestation: Modelling the impact of population, market forces and property rights. J. Dev. Econ. 58:185-218.

Arnold JG, Allen PM, Bernhardt G (1993). A comprehensive surface-groundwater flow model. J. Hydrol. 142:47-69

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998). Large area hydrologic modeling and assessment. Part 1: Model development. J. Amer. Water Res. Assoc. 34(1):73-89.

Barbier EB (2004). Explaining agricultural land expansion and deforestation in developing countries. Amer. J. of Agr. Econ. 86(5):1347-1353.

Bari M, Smettem KRJ (2004). Modeling monthly runoff generation processes following land use changes: Groundwater-surface water interactions. Hydrol. Earth Syst. Sci. 8(5):903-922.

Bates CG (1921). First results in the streamflow experiment, Wagon Wheel Gap, Colorado. J. Forest. 19(4):402-408.

Bates CG, Henry AJ (1928). Forest and streamflow experiments at Wagon Wheel Gap, Colorado. U.S. Weather Bureau Monthly weather review, Suppl. No. 30. pp. 79.

Beven K, Calver A, Morris EM (1987). The Institute of Hydrology distributed model. Institute of Hydrology Report 98. Wallingford, UK.

Bosch JM, Hewlett JD (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55:3-23.

Chaves J, Neill C, Germer S, Neto SG, Krusche A, Elsenbeer H (2008). Land management impacts on runoff sources in small Amazon watersheds. Hydrol. Proc. 22:1766-1775.

Dagg M, Blackie JR (1965). Studies of the effects of changes in land use on the hydrological cycle in East Africa by means of experimental catchment areas. Int. Assoc. Sci. Hydrol. Bull 10(4):63-75.

Dunford EG, Fletcher PW (1947). Effect of removal of stream-bank vegetation upon water yield. Trans. Amer. Geophys. Union 28(1):105-110.

Edwards KA, Blackie JR (1981). Results of the East African catchment experiments 1958-1974. Trop. Agric. Hydrol. Edited by Lal, R. and Russel, E.W., John Wiley and Sons Ltd.

Fohrer N, Haverkamp S, Eckhardt K, Frede HG (2001). Hydrologic response to land use changes on the catchment scale. Phys. Chem. Earth (B) 26(7-8):577-582.

Gebresamuel G, Singh BR, Dick O (2010). Land-use changes and their impacts on soil degradation and surface runoff of two catchments of Northern Ethiopia, Acta Agricult. Scandinavica, Section B - Soil Plant Sci. 60 (3):211-226.

Greenwood AJB, Benyon RG, Lane PNJ (2011). A method for assessing the hydrological impact of afforestation using regional mean annual data and empirical rainfall-runoff curves. J. Hydrol. 411:49-65.

Hegg C, McArdell BW, Badoux A (2006). One hundred years of mountain hydrology in Switzerland by the WSL. Hydrol. Proc. 20:371-376.

Hessling M (1999). Hydrological modelling and a pair basin study of Mediterranean. Phys. Chem. Earth (B) 24(l-2):59-63.

Hibbert AR (1967). Forest treatment effects on water yield. In "Forest Hydrology", Sopper WE, Lull HW (eds.), Pergamon, Oxford, 813 pp.

Hundecha Y, Bardossy A (2004). Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model. J. Hydrol. 292:281-295.

Hurni H, Tato K, Zeleke G (2005). The implications of changes in population, land use and land management for surface runoff in the Upper Nile basin area of Ethiopia. Mount. Res. Dev. 25(2):147-154.

Iroume A, Huber A, Schulz K (2005). Summer flows in experimental catchments with different forest covers, Chile. J. Hydrol. 300:300-313.

Jinno K, Tsutsumi A, Alkaeed O, Saita S, Berndtsson R (2009). Effects of land-use change on groundwater recharge model Parameters. Hydrol. Sci. J. 54(2):301-315.

Kendall MG (1955). Rank correlation Methods, Charles Griffin, London.

Li Q, Cai T, Yu M, Lu G, Xie W, Bai X (2010). Investigation into the impacts of land-use change on runoff generation characteristics in the upper Huaihe River basin, China. J. Hydrol. Eng. DOI:10.1061/(ASCE) HE.1943-5584.0000489.

Li H, Zhang Y, Vaze J, Wang B (2012). Separating effects of vegetation change and climate variability using hydrological modelling and sensitivity-based approaches. J. Hydrol. (420-421):403-418.

Lorup JK, Refsgaard JC, Mazvimavi D (1998). Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: Case studies from Zimbabwe. J. Hydrol. 205:147-163.

Mann HB (1945). Nonparametric tests against trend. Econometrica, 13:245-259.

Mati BM, Mutie S, Gadain H, Hame P, Mtalo F (2008). Impacts of land-use/cover changes on the hydrology of the transboundary Mara River, Kenya/Tanzania, Lakes Reservoirs. Resour. Manag. 13(1):169-177.

McCann JC (1997). The Pillow and the forest: Narratives of deforestation in Ethiopia, 1840-1992. Environ. Hist. 2(2):138-159.

Nemec J, Pasak, V, Zeleny V (1967). Forest hydrology research in Czechoslovakia. In Sopper, WE and Lull, HW (Eds): Int. Symposium on Forest Hydrology, Pergamon Press, New York, pp. 31-33.

Piao S, Friedlingstein P, Ciais P, de Noblet-Ducoudre N, Labat D, Zaehle S (2007). Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. Proc. Nat. Acad. Sci. 104(39):15242-15247.

Refsgaard JC, Alley WM, Vuglinsky VS (1989). Methods for distinguishing between man's influence and climatic effects on the Hydrological cycle. IHP-III Project 6.3, UNESCO, Paris.

Rientjes THM, Haile AT, Mannaerts CMM, Kebede E, Habib E, Steenhuis TS (2011). Changes in land cover and stream flows in Gilgel Abbay catchment, Upper Blue Nile basin – Ethiopia. Hydrol. Earth Syst. Sci. 15:1979-1989.

Shi PJ, Yuan Y, Zheng Z, Wang JA, Ge Y and Qiu GY (2007). The effect of land use/cover change on surface runoff in Shenzhen region, China. Catena 69:31-35.

Seibert J, McDonnel JJ (2010). Land-cover impacts on streamflow: A change-detection modelling approach that incorporates parameter uncertainty. Hydrol. Sci. J. 55(3):316-332.

Syvitski JPM, Milliman, JD (2007). Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean. J. Geol., 115:1-19.

Troendle CA, King RM (1987). The effect of partial and clearcutting on streamflow at deadhorse creek, Colorado. J. Hydrol. 90:145-157.

Tiwari SP, Kurothe RS (2006). Effect of vegetative barriers on soil and nutrients losses at 2% slope on agricultural lands of reclaimed Mahi ravines. Indian J. Soil Conserv. 34(1):37-41.

Vitousek PM (1994). Beyond global warming: Ecology and global Change. Ecology 75(7):1861-1876.

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997). Human domination of Earth's ecosystems. Science 277.

Wight CL (1940). A preliminary account of rainfall in Jonkershoek. Trans. Royal Soc. South Afr. 28 (2):161-73.

Wight CL (1943). Determination of the effects of watershed management on mountain streams. Amer. Geophys. Union Trans. 2:594-608.

Yang Y, Tian F (2009). Abrupt change of runoff and its major driving factors in Haihe River Catchment, China. J. Hydrol. 374:373-383.

Yu DS, Shi XZ, Wang HJ, Zhang XY, Weindorf DC (2008). Functions of soils in regulating rainwater in Southern China: Impacts of land uses and soils. Pedosphere 18(6):717-730.

Zeleke G, Hurni H (2001). Implications of land use and land cover dynamics for mountain resource degradation in the northwestern Ethiopian highlands. Mount. Res. Dev. 21(2):184-191.

Zhang S, Lu XX (2006). Long-term water and sediment change detection in a small mountainous tributary of the lower pearl river, china. Adv. Geosci., Hydrological Science (eds.) Namsik Park et al., World Scientific Publishing Company, 6:97-108,

Zhao RJ, Zhang YL, Fang LR, Liu XR, Zhang QS (1980). The Xinanjiang model. In: Hydrological Forecasting Proceedings Oxford Symposium. IASH, pp. 351-356.

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Full Length Research Paper

Heavy metals assessment of private drinking water supplies in Ibadan, Nigeria and associated health risks

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The aim was to measure the concentrations of heavy metals in groundwater obtained from 30 randomly selected domestic wells and 10 stream locations all in Ibadan, Nigeria, compare the results with the World Health Organization guidelines, draw conclusions and make recommendations. Water samples were obtained and analysed for Pb, As, Cd, Zn, Cu, Cr, Fe and Mn. Overall, the minimum concentrations of Pb, As, Cd, Cr and Fe in the well water samples were below detection limit (BDL). The maximum values were 0.02, 0.45, 0.01, 0.445, 0.135, 0.09, 0.245 and 0.155 mg/l respectively. In the surface water samples, the minimum concentrations of Pb, As, Cd and Cr were below detection level, while the maximum concentrations of Pb, As, Cd, Zn, Cu, Cr, Fe and Mn were respectively 0.075, 0.05, 0.001, 0.445, 0.120, 0.065, 0.45 and 0.16 mg/l. No evidence of contamination of these water supply sources with heavy metals was found going by the fact that the values obtained were lower than the guideline values established by the World Health Organization. A possible exception is As which in some samples had higher concentrations than the WHO guideline. The recommendations of the study include continuous and close monitoring of these private drinking water supplies. There must also be strict compliance to regulatory limits in sludge and wastes to be released into the environment, and enforcement of other environmental protection regulations. Findings from this study will be of immense help to the general public as well as researchers and environmental regulators working in this area of interest in developing countries.

Key words: Heavy metals, drinking water, Ibadan

INTRODUCTION

Begun et al. (2009) observed that large quantities of pollutants have continuously been introduced into ecosystems as a consequence of urbanization and industrial processes. Metals are persistent pollutants that can be biomagnified in the food chains, and natural waters, becoming increasingly dangerous to human beings and wildlife. The use of private wells and surface sources to provide water for domestic purposes in both urban areas and rural communities is a common practice in Nigeria and communities all over Africa (Adelekan and Ogunde, 2012; Adetunji and Odetokun, 2011; Adelekan, 2010). Therefore, assessing the concentrations of pollutants in different components of the ecosystem has become an important task in preventing risk to natural life and public health. Heavy metals enter into the environment mainly via three routes namely: (i) deposition of atmospheric particulate; (ii) disposal of metal enriched sewage sludges, sewage effluents and solid wastes, as well as (iii) by-products from metal mining process. Corrosion of metallic installations, ash

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amendment to manures for odor reduction and lime amendment for disinfection purposes are other possible sources of heavy metals, e.g. lead, cadmium, chrome, zinc and nickel (Eckel, 2005). Air pollution caused by the emissions of toxic metals is one of the main types of environmental pollution, and it has been recognized as a potential threat to both environment and human health. Ingestion, dermal contact absorption and inhalation are the main routes of air particle metals entering human bodies (Shi et al., 2011). All these readily happen in urban environments. Soil is one of the repositories for anthropogenic wastes. Biochemical processes can mobilize its content of wastes to pollute water supplies and impact food chains. Heavy metals such as Pb, As, Cd, Zn, Cu, Cr, Fe, and Mn are potential soil and water pollutants.

Globally, the problem of environmental pollution due to heavy metals has begun to cause concern in most large cities since this may lead to geoaccumulation, bioaccumulation and biomagnifications in ecosystems. Ibadan (7°23’47” N 3°55’0” E) is one of the three largest metropolises in Nigeria. It occupies an area of 828 km^2 and has a population of approximately 2.6 million according to the 2006 census (NPC, 2009). Reported researches in respect of water quality in the city of Ibadan, Nigeria include Adelekan and Abegunde (2011) which investigated the heavy metals contamination of soils and groundwater at automobile mechanic villages in the city and Adelekan and Alawode (2011) which assessed the contributions of municipal refuse dumps to heavy metals concentrations in soil profile and groundwater on the dump sites in the city. The two papers reported that the concentrations of certain heavy metals are steadily increasing due to industrial activities and waste dumping at those locations studied. With that position established, the objective of this research is to investigate the concentrations of these heavy metals in domestic water sources at residences in the city in order to establish the presence or otherwise of any health risks to the city residents. From observations, appropriate remedies can then be proposed for the protection of human health and the environment. It is with that objective in mind that this research work was undertaken.

MATERIALS AND METHODS

Water samples were obtained from 10 locations on Odo Ona and Ogunpa streams which are important surface water sources used for domestic purposes by Ibadan residents. Samples were also obtained from 30 wells on private residences scattered throughout the city following standard water sampling procedure. The wells ranged from 8 to 10 m in depth, and were lined to ensure recharge from the bottom only. Three replicates were sampled at each location. Each sample was directly collected into a factory-fresh 1.5 L plastic bottle, with cap securely tightened. This ensured there was no prior contamination, and there was no possibility of contamination after sampling that could affect the samples and invalidate results obtained. After collection the bottles were placed inside ice coolers for transportation to the laboratory where they were then transferred to the refrigerator. This ensured that any form of microbial activity due for example to iron bacteria, occurring after sampling, would be stopped or severely curtailed. Laboratory analysis commenced the same day. The methods used are described in APHA et al. (1998). Readings were made on the Atomic Absorption Spectrophotometer (AAS). These investigations were conducted in November 2011.

RESULTS

Results obtained are presented in the tables and figure. From Table 1, it is noticed that the concentration of each of the heavy metals in most of the surface water samples met the guidelines of the World Health Organization (2004a). From Table 2, it is noticed that the maximum and minimum concentrations of heavy metals occurred variously in different surface water samples. From Table 3, it is noticed that the concentration of each of the heavy metals in most of the well water samples met the guidelines of the World Health Organization (2004a). Measurements for well water samples obtained from the tables are plotted in the following figures.

Figure 1 shows that Pb concentration in the well samples ranged from 0 (that is, below detection limit) to 0.02 mg/l. The trendline started around 0.005 mg/l and dipped slightly as well number changed from 1 to 30.

Figure 2 shows that As concentration in the well samples ranged from 0 (that is, below detection limit) to 0.055 mg/l (well number 18). The trendline started at 0.03 mg/l and dipped strongly to about 0.02 mg/l as well number changed from 1 to 30.

Figure 3 shows that Zn concentration in the well samples ranged from 0.12 (well 18) to 0.445 mg/l (well 26). The trendline started around 0.35 mg/l and climbed slightly above that value as the well number changed from 1 to 30.

Figure 4 shows that Cu concentration in the well samples ranged from 0.07 mg/l (well 14) to 0.135 mg/l (wells 12, 13, 17 and 25). The trendline started around 0.104 mg/l and remained practically on the same level as well number changed from 1 to 30.

Figure 5 shows that Cr concentration in the well samples ranged from 0 (that is, below detection limit) to 0.15 mg/l. The trendline started around 0.04 mg/l and dipped slightly as well number changed from 1 to 30.

Figure 6 shows that Fe concentration in the well samples ranged from 0 (1 sample) (that is, below detection limit) to 0.025 mg/l. The trendline started around 0.16 mg/l and dipped slightly as well number changed from 1 to 30.

Figure 7 shows that Mn concentration in the well samples ranged from 0.07 to 0.16 mg/l. The trendline started around 0.12 mg/l and dipped slightly as well number changed from 1 to 30.

Figure 8 shows that Cu concentration in the well samples ranged from 0.13 to 0.45 mg/l. The trendline started around 0.34 mg/l and raised slightly as well number changed from 1 to 30. Zn concentration ranged

Table 1. Heavy metals concentrations in surface water samples (mg/l).

Sample	Pb	As	Cd	Zn	Cu	Cr	Fe	Mn
S1	BDL	0.050	BDL	0.280	0.090	0.050	0.225	0.135
S2	0.050	BDL	0.001	0.280	0.105	BDL	0.175	0.105
S3	BDL	0.035	0.001	0.435	0.085	0.050	0.180	0.145
S4	0.010	BDL	BDL	0.295	0.105	0.065	0.450	0.135
S5	BDL	BDL	BDL	0.355	0.110	BDL	0.225	0.105
S6	0.075	0.050	BDL	0.295	0.105	BDL	0.185	0.125
S7	0.007	0.035	0.001	0.385	0.075	0.035	0.205	0.160
S8	0.010	0.030	BDL	0.405	0.085	BDL	0.205	0.100
S9	BDL	0.040	BDL	0.335	0.120	BDL	0.250	0.105
S10	BDL	0.040	BDL	0.445	0.105	0.060	0.270	0.135
Average	0.015	0.028	0.0003	0.351	0.099	0.026	0.233	0.125
WHO guideline	0.01	0.01	0.003	3	1	0.050	0.30	0.200

Values are means of 3 measurements; BDL, below detection limit in the sample analysed.

Table 2. Maximum and minimum measured concentrations of heavy metals in surface water samples (mg/l).

Heavy metal	Measured limits		Sample of occurrence
Pb	Maximum	0.075	S6
	Minimum	BDL	S1, S3, S5, S9, S10
As	Maximum	0.050	S1
	Minimum	BDL	S2, S4, S5
Cd	Maximum	0.001	S2, S3, S7
	Minimum	BDL	S1, S4, S5, S6, S8, S9, S10
Zn	Maximum	0.445	S10
	Minimum	0.280	S1, S2
Cu	Maximum	0.120	S9
	Minimum	0.085	S3, S8
Cr	Maximum	0.065	S4
	Minimum	BDL	S2, S5, S6, S8, S9
Fe	Maximum	0.450	S4
	Minimum	0.175	S2
Mn	Maximum	0.160	S7
	Minimum	0.100	S8

BDL, Below detection limit in the sample analysed.

from 0.07 to 0.15 mg/l and its trendline starting around 0.1 mg/l remained level. Concentration of Zn was more than that of Cu in all the samples. Figure 9 shows that Cr concentration in the well samples ranged from 0 (that is, below detection limit) to 0.25 mg/l. The trendline started around 0.16 mg/l and dipped slightly as well number changed from 1 to 30. Fe concentration ranged from 0 (below detection limit) and peaked at 0.12 mg/l. Its trendline dipped slightly from 0.04 mg/l. For the majority of samples, the concentration of Cr was higher than that of Fe.

Figure 10 shows that Mn concentration in the well samples ranged from 0.08 to 0.15 mg/l. The trendline started around 0.12 mg/l and dipped slightly as well number changed from 1 to 30. As ranged from 0 (below detection limit) to 0.06 mg/l, while its trendline started

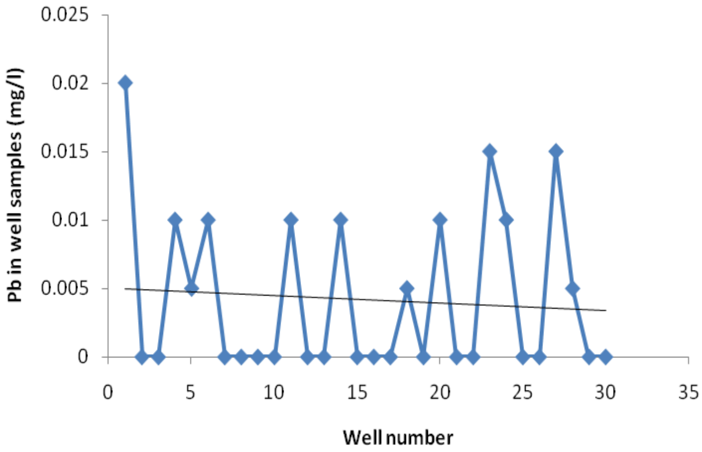

Figure 1. Lead in well water samples.

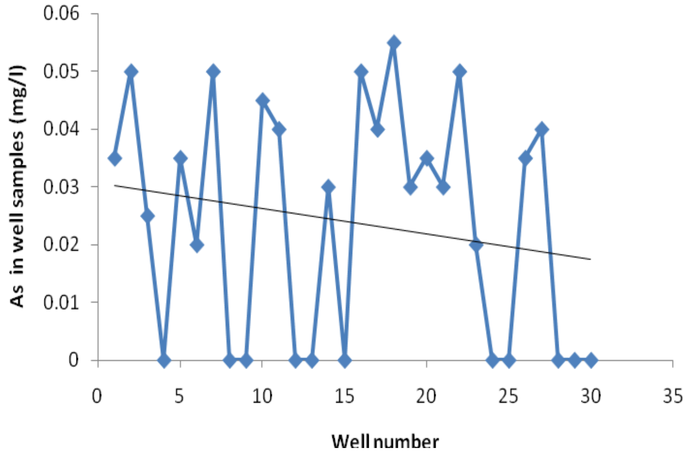

Figure 2. Arsenic in well water samples.

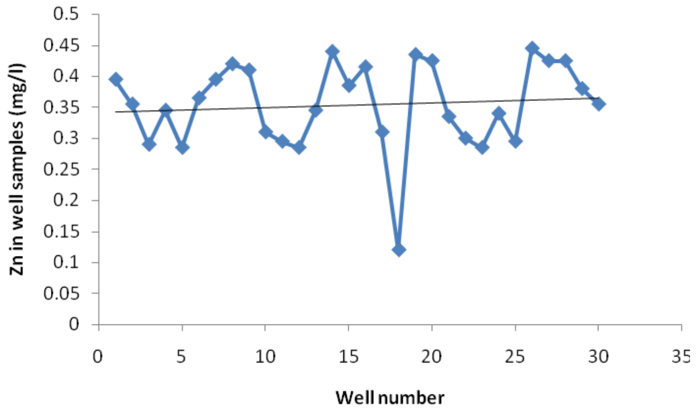

Figure 3. Zinc concentration in well water samples.

around 0.03 mg/l and dipped slightly. Concentrations of manganese were clearly higher than those of As in all the samples.

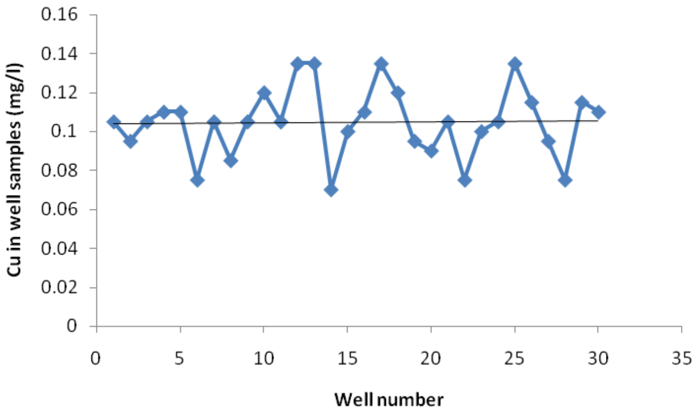

Figure 4. Copper in well water samples.

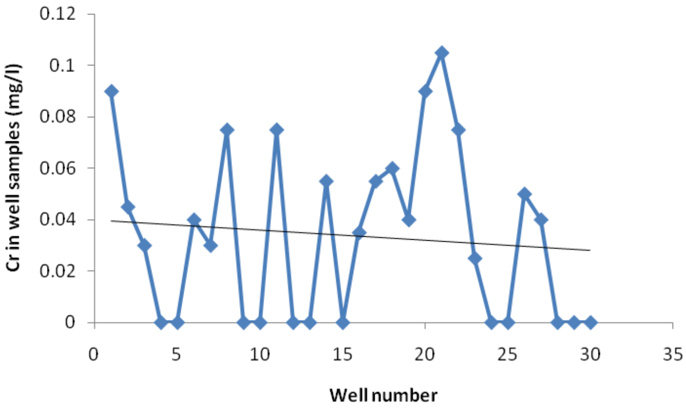

Figure 5. Chromium in well water samples.

DISCUSSION

Table 1 shows the concentrations of heavy metals in surface water samples obtained from 10 locations, the average values as well as the WHO (2004a) guidelines. With the exception of Cr and Fe, concentrations of heavy metals measured were lower than the WHO guideline values, for all samples. In fact, values were below detection limits (BDL) in 5, 3, 7, and 5 locations for Pb, As, Cd, and Cr respectively. For Zn and Cu in particular, concentrations measured were far below the WHO guideline values. For Cr, concentration above WHO guideline value was measured in two out of the ten locations, while for Fe just one location had a concentration higher than the WHO guideline value.

Table 2 shows the maximum and minimum concentrations of the heavy metals as well as their samples of occurrence. For Pb, the maximum concentration of 0.075 mg/l occurred in sample S6, and this sample also had the minimum concentrations for Cd and Cr, in both cases, below detection limits. The maximum values of 0.065 and 0.45 mg/l measured for Cr and Fe respectively shown in Table 2 were higher than

Table 3. Concentrations of heavy metals measured in well water samples (mg/l).

Sample	Pb	As	Cd	Zn	Cu	Cr	Fe	Mn
W1	0.020	0.035	BDL	0.395	0.105	0.090	0.140	0.155
W2	BDL	0.050	BDL	0.355	0.095	0.045	0.160	0.090
W3	BDL	0.025	0.010	0.290	0.105	0.030	0.090	0.095
W4	0.010	BDL	BDL	0.345	0.110	BDL	0.130	0.120
W5	0.005	0.035	BDL	0.285	0.110	BDL	0.145	0.125
W6	0.010	0.020	BDL	0.365	0.075	0.040	0.185	0.145
W7	BDL	0.050	BDL	0.395	0.105	0.030	0.195	0.105
W8	BDL	BDL	BDL	0.420	0.085	0.075	0.220	0.105
W9	BDL	BDL	BDL	0.410	0.105	BDL	0.150	0.085
W10	BDL	0.045	BDL	0.310	0.120	BDL	0.205	0.085
W11	0.010	0.040	BDL	0.295	0.105	0.075	0.155	0.115
W12	BDL	BDL	BDL	0.285	0.135	BDL	0.195	0.110
W13	BDL	BDL	BDL	0.345	0.135	BDL	0.215	0.115
W14	0.010	0.030	BDL	0.440	0.070	0.055	0.245	0.135
W15	BDL	BDL	0.001	0.385	0.100	BDL	BDL	0.140
W16	BDL	0.050	BDL	0.415	0.110	0.035	0.090	0.150
W17	BDL	0.040	BDL	0.310	0.135	0.055	0.105	0.085
W18	0.005	0.055	BDL	0.120	0.120	0.060	0.100	0.110
W19	ND	0.030	BDL	0.435	0.095	0.040	0.105	0.130
W20	0.010	0.035	0.005	0.425	0.090	0.030	0.145	0.085
W21	BDL	0.030	BDL	0.335	0.105	0.035	0.105	0.100
W22	BDL	0.050	BDL	0.300	0.075	0.025	0.150	0.100
W23	0.015	0.020	BDL	0.285	0.100	0.025	0.095	0.140
W24	0.010	BDL	0.001	0.340	0.105	BDL	0.075	0.115
W25	BDL	BDL	0.001	0.295	0.135	BDL	0.135	0.135
W26	BDL	0.035	0.001	0.445	0.115	0.050	0.155	0.135
W27	0.015	0.040	BDL	0.425	0.095	0.040	0.220	0.075
W28	0.005	BDL	BDL	0.425	0.075	BDL	0.125	0.100
W29	BDL	BDL	BDL	0.380	0.115	BDL	0.170	0.090
W30	BDL	BDL	BDL	0.355	0.110	BDL	0.160	0.105
Average	0.006	0.02	0.001	0.354	0.105	0.03	0.15	0.1
WHO guideline	0.01	0.01	0.003	3	1	0.05	0.3	0.2

Values are means of 3 measurements; BDL, below detection limit in the sample analysed.

the WHO (2004a) guidelines of 0.05 and 0.3 mg/l (Table 1). All the other values measured are certainly within the WHO guidelines, and consumers do not appear to be exposed to heavy metal contamination through these water samples. Table 3 shows the concentrations of heavy metals in water samples obtained from 30 private water wells, their average values as well as the WHO (2004a) guideline values. Cd appears to be the rarest heavy metal in these samples. Its concentration was below detection limit in 77% of the wells. In 20% of the well samples, the concentration of Cd measured was lower than the WHO (2004a) guideline, while it was higher in 3% of the samples. Pb, As and Cr were measured to be below detection limit in 60, 37 and 40% of the well samples respectively. Although, Zn, Cu and Mn were found in all the water samples, their concentrations were however below the WHO guidelines.

For the majority of samples, the average concentrations for all the heavy metals were lower than the WHO (2004a) guideline values. The only exception to this was sample W1 in which 0.09 mg/l was measured for Cr while the WHO guideline value was 0.05 mg/l. Table 4 shows average concentrations of heavy metals measured in surface and well water samples as compared to the WHO (2004a) guidelines. Regarding the well samples, all the average values are lower than the guidelines. Regarding the surface water samples, average concentrations measured for Cd, Zn, Cu, Cr, Fe, and Mn were lower than the WHO guidelines. Average concentrations of Pb and As were slightly higher than the guidelines. Table 5 shows the maximum and minimum concentrations of heavy metals measured in the well water samples. Comparing Table 5 and Table 2, it is noticed that for Pb, Fe and Mn, the maximum concentrations measured in

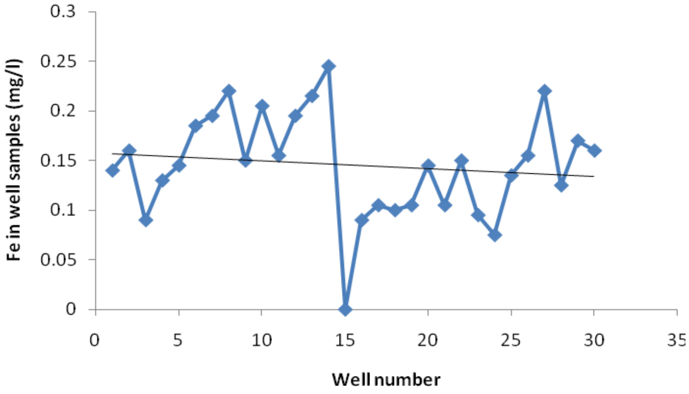

Figure 6. Iron in well water samples.

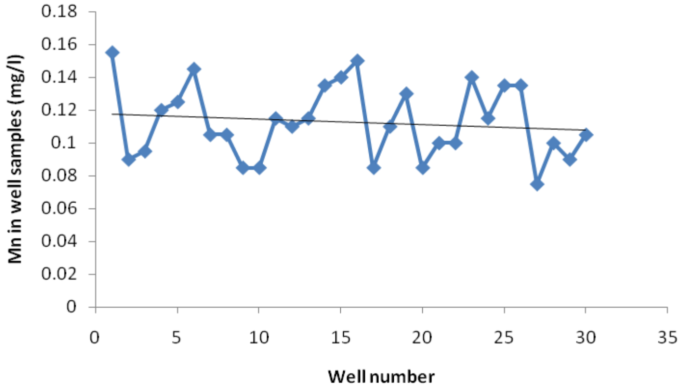

Figure 7. Manganese in well water samples.

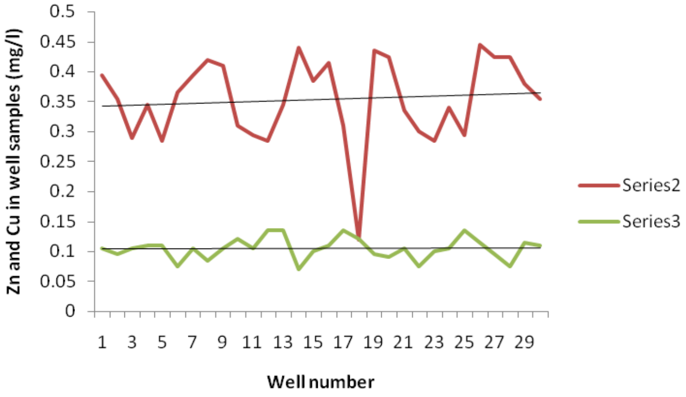

Figure 8. Concentrations of Zn (series 2) and Cu (series 3) in well water samples.

well water samples were less than those measured for surface water samples. The reverse is the case for As, Cd, Cu and Cr; while for Zn, it was the same value for both well water and surface water samples.

According to USDA (2000), acute (immediate) poisoning from heavy metals is rare through ingestion or dermal contact, but it is possible. Chronic problems associated with long-term heavy metal exposures are mental lapse (lead); toxicological effects on kidney, liver and gastrointestinal tract (cadmium); skin poisoning and harmful effects on kidneys and the central nervous system (arsenic). There is a link between long term exposure to copper and decline of intelligence in young adolescents (Lenntech, 2009). Chronic cadmium exposures result in kidney damage, bone deformities, and cardiovascular problems (Goyer and Clarkson, 2001). Human diseases have resulted from consumption of cadmium contaminated foods (Kobayashi, 1978; Nogawa et al., 1987). The threat that heavy metals pose to human and animal health is aggravated by their low environmental mobility, even under high precipitations, and their long term persistence in the environment (Mench et al., 1994; Chirenje et al., 2004).

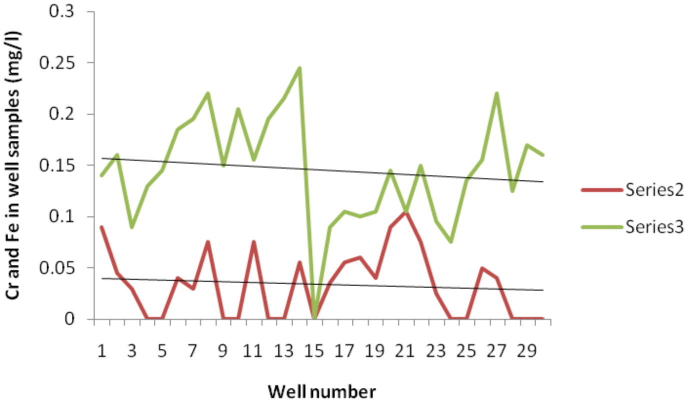

Figure 9. Concentrations of Cr (series 2) and Fe (series 3) in well water samples.

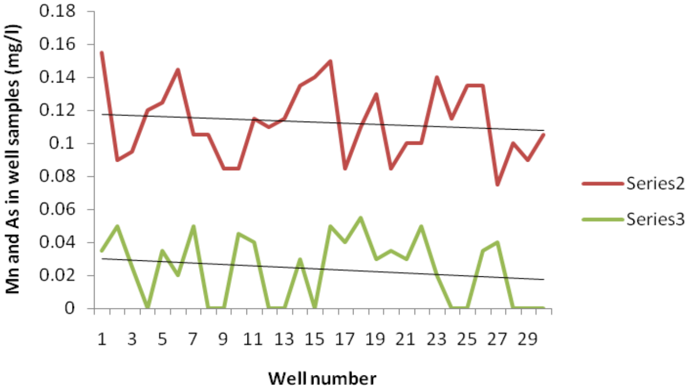

Figure 10. Concentrations of Mn (series 2) and As (series 3) in well water samples.

USEPA (2004) noted that manganese is an essential element for many living organisms including human beings. It is necessary for proper functioning of some enzymes (manganese superoxide dismutase) and for the activation of others (notably kinases, decarboxylases). Adverse health effects can be caused by inadequate intake or overexposure. The average concentration of manganese

Table 4. Average concentrations of heavy metals measured in surface water and well water samples (mg/l).

Description	Pb	As	Cd	Zn	Cu	Cr	Fe	Mn
Surface water	0.015	0.028	0.0003	0.351	0.099	0.026	0.233	0.125
Well water	0.006	0.02	0.001	0.354	0.105	0.03	0.15	0.1
WHO guideline	0.01	0.01	0.003	3	1	0.05	0.3	0.2

Table 5. Maximum and minimum measured concentrations of heavy metals in well water samples (mg/l).

Heavy metal	Measured limits		Sample of occurrence
Pb	Maximum	0.020	W1
	Minimum	BDL	18 different samples
As	Maximum	0.450	W10
	Minimum	BDL	11 different samples
Cd	Maximum	0.010	W3
	Minimum	BDL	24 different samples
Zn	Maximum	0.445	W26
	Minimum	0.120	W18
Cu	Maximum	0.135	W12, W13, W17, W25
	Minimum	0.070	W14
Cr	Maximum	0.090	W1
	Minimum	BDL	12 different samples
Fe	Maximum	0.245	W14
	Minimum	BDL	W15
Mn	Maximum	0.155	W1
	Minimum	0.075	W27

BDL, Below detection limit in the sample analysed.

measured in all the well samples was 0.1 mg/l while the surface samples averaged 0.125 mg/l. These low values however should not be of much concern since manganese deficiency in human beings appears to be rare because manganese is present in many common foods. According to WHO (2004b), a health-based guideline value of 0.4 mg/l should be adequate to protect public health. Excessive levels of Mn in the brain produces extra pyramidal symptoms similar to those in patients with Parkinson’s disease (Stredrick et al., 2002), decreased learning ability in school age children and increased propensity for violence in adults (Finley, 2004). According to the Wisconsin Department of Health and Family Services (2007), manganese levels below 300 µg/l are generally not a health concern. Infants should not drink water that is above the health advisory level of 300 µg/l. Many years of exposure to high levels of manganese can cause harm to the nervous system. A disorder similar to Parkinson’s disease can result.

Frequently found in water due to large deposits in the earth’s crust, iron, is also an important heavy metal from the point of view of human health and aesthetics. In the presence of hydrogen sulfide, iron causes sediment to form that may give the water a blackish color. WHO (2004a) has a guideline value of 0.3 mg/l of iron in drinking water. A range of 0 to 0.22 mg/l was measured for the well samples in this study (Table 3), while the range measured in the surface samples was 0.175 to 0.450 mg/l (Table 1). In only one sample was Fe measured to be above 0.3 mg/l which is the WHO (2004a) guideline value. All the other samples contained iron at concentrations lower than the WHO guideline. The Illinois Environmental Protection Agency (IEPA) has established a maximum concentration for iron in drinking water of 1.0 mg/l and this is even a more relaxed value than the WHO guideline. According to WHO (2004c), anaerobic groundwaters may contain iron (II) at concentrations up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. Taste is not usually noticeable at iron concentrations below 0.3 mg/l, although turbidity and colour may develop in piped systems at levels above 0.05 to 0.1 mg/l. Laundry and sanitary ware will stain at iron concentrations above 0.3 mg/l. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day.

Heavy metals are regularly found in liquid pig manure (Gerber et al., 2005). Animal feeding is supposed to be the main source of occurrence for copper and zinc (Li et al., 2007; Nicholson et al., 1999). Mineral feed may also contribute to occurrence of cadmium, lead, arsenic and mercury (de La Calle Guntinas et al., 2011). Livestock rearing is a common activity in urban agriculture and this also occurs in Ibadan. Corrosion of metallic installations, ash amendment to manures for odor reduction and lime amendment for disinfection purposes are other possible sources of heavy metals, e.g. lead, cadmium, chromium, zinc and nickel (Eckel, 2005). Arsenic (As) is a well-known heavy metal which is ubiquitous in the environment (Vahidnia et al., 2007; Garelick et al., 2008). Arsenic is classified as a poison and its exposure is mainly through ingestion and inhalation of arsenic-bearing chemicals from drinking water, food, and air (Rahman et al., 2009; Aposhian et al., 2004). Once it enters the body, arsenic and its metabolites generate free radicals, which damage proteins, fatty acids, DNA, and RNA, and cause oxidative stress or death to cells (Gong and O'Bryant, 2010). Inflammatory response is one of the hallmarks of arsenic-induced toxicity (Valko et al., 2005). Clinically, arsenic is well-known as a carcinogen, causing prostate, lung, liver, bladder, and other cancers (Jomova et al., 2011; Mink et al., 2008; Benbrahim-Tallaa and Waalkes, 2008; Celik et al., 2008; Chiu et al., 2004).

The measured well water arsenic concentrations ranged from 0 to 0.05 mg/l with a mean of 0.02 mg/l (Tables 3 and 4), while the surface water arsenic concentrations ranged from 0 to 0.05 mg/l with a mean of 0.028 mg/l (Tables 1 and 4). The WHO guideline value is 0.01 mg/l. It is conclusive that as far as arsenic is concerned, concentrations in many of these samples were higher than the WHO guideline. The difference is however not presently alarming. Previous studies have shown that cancer risk increases by 100-fold among people exposed to drinking water with arsenic concentration at 50 mg/l (Smith et al., 2002). As a result, U.S. Environmental Protection Agency (USEPA) set the current standard concentration of arsenic in drinking water to10 mg/l effective in 2006 in the United States (Smith et al., 2002). Concentrations found in this present research were far lower than this. A paper by Liao et al. (2009) reported that bladder cancer risk increased significantly among Taiwanese men with long-term chronic arsenic exposure at low level and noted that a recommended safe arsenic level in drinking water is 3.4 mg/l, far below the current USEPA standard, 10 mg/l. The National Research Council (2001) has recommended examining the effect of low-level arsenic exposure on health outcomes. Arsenic exposure not only causes cancer but also increases the risks of many other diseases. Chen et al. (1988) reported that compared with the general population, mortality rates from cardiovascular diseases, peripheral vascular diseases, as well as cancers of bladder, skin, lung, and liver were significantly higher among patients with blackfoot disease resulting from exposure to high concentrations of arsenic (from 350 to 1140 ppb or mg/l with a median of 780 mg/l) in certain areas in Taiwan. Tseng et al. (2003) reported that ischemic heart disease prevalence was significantly correlated with cumulative arsenic exposure (arsenic concentration multiplied by the number of years individuals had lived there) in arseniasis-hyperendemic villages in Taiwan. A dose–response relationship existed between ischemic heart disease mortality and long-term arsenic exposure (Chen et al., 1996). Coronary heart disease and hypertension were associated with low-level arsenic exposure, while coronary heart disease and hyperlipidemia were associated with AS3MT polymorphism in a rural cohort in Texas, USA (Gong and O'Bryant, 2012).

The concentration of Chromium in the well water samples was found to range from 0 to 0.09 mg/l with a mean of 0.03 mg/l. In the surface water samples, Cr was measured from a range of 0 to 0.065 mg/l with a mean of 0.026 mg/l. The WHO (2004a) guideline value for Cr in drinking water is 0.05 mg/l. Chromium is one of those heavy metals the environmental concentration of which is steadily increasing due to industrial growth, especially the development of metal, chemical and tanning industries. Other sources of chromium permeating the environment are air and water erosion of rocks, power plants, liquid fuels, brown and hard coal, and industrial and municipal waste. Although there is no risk of chromium contamination on a global scale, local permeation of the metal to soil, water or the atmosphere might result in excessive amounts of this pollutant in biogeochemical circulation (Wyszkowska, 2002). As observed by Ghosh and Singh (2005) non-biodegradability of chromium is responsible for its persistence in the environment; once mixed in soil, it undergoes transformation into various mobile forms before ending into the environmental sink (Bartlett and James, 1983; Bartlett, 1988). Although Cr toxicity in the environment is relatively rare, it still presents some risks to human health since chromium can be accumulated on skin, lungs, muscles fat, and it accumulates in liver, dorsal spine, hair, nails and placenta where it is traceable to various heath conditions (Reyes-Gutiérrez et al., 2007).

CONCLUSIONS AND RECOMMENDATIONS

Overall, the minimum concentrations of Pb, As, Cd, Cr and Fe in the well water samples were below detection limit (BDL), while the maximum concentrations were 0.02, 0.055, 0.01, 0.09, and 0.245 mg/l. For Zn, Cu and Mn, the minimum concentrations were 0.120, 0.135 and 0.075 mg/l and the maximum concentrations were 0.0445, 0.135 and 0.155 mg/l respectively. Similar results were also obtained for the surface water samples. There is therefore no evidence of wide-scale contamination of these water samples with heavy metals going by the fact that most of the values measured were well within the guideline limits established by the World Health Organization. A possible exception is As which showed values higher than the WHO guideline. The recommend-dations of the study include continuous and close monitoring of these private drinking water supplies in view of increasing urbanization and industrialization of the town in which they are situated. There must also be strict compliance to regulatory limits in sludge and wastes to be released into the environment as well as enforcement of other environmental protection regulations to arrest the earlier reported ongoing buildup of heavy metals in soils on those locations. Findings from this study will be of immense help to the consumers of these waters as well as researchers and environmental regulators working in this area of interest in developing countries. On one hand the consumers have a scientific basis for assessing the quality of the water which they are using. On the other hand researchers also have useful scientific knowledge on the water supply situation in Ibadan, which is a typical African city. and this they can apply in finding solutions to problems which they may encounter in similar situations existing around the African continent.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Adelekan BA (2010). Water quality of domestic wells in typical african communities: case studies from Nigeria. Int. J. Water Res. Environ. Eng. 2(6):137-147, September. Published online at www.academicjournals.org/IJWREE

Adelekan BA, Abegunde KD (2011). Heavy metals contamination of soil and groundwater in automobile mechanic villages in Ibadan, Nigeria. Int. J. Phy. Sci. 6(5):1045-1058. March 4. Available online at www.academicjournals.org/IJPS

Adelekan BA, Alawode AO (2011). Contributions of municipal refuse dumps to heavy metals concentrations in soil profile and groundwater in Ibadan, Nigeria. J. Appl. Biosci. 40:2727-2737. Available online at www.m.elewa.org/JABS

Adelekan BA, Ogunde OA (2012). Quality of water from dug wells and the lagoon in Lagos Nigeria and associated health risks. Sci. Res. Essays. 7(11):1195-1211. Available online at www.academicjournals.org/SRE

Adetunji VO, Odetokun IA (2011). Groundwater contamination in Agbowo community, Ibadan, Nigeria: Impact of septic tanks distances to wells. Mal. J. Mocrobiol. 7(3):159-166.

Aposhian HV, Zakharyan RA, Avram MD, Sampayo-Reyes A, Wollenberg ML (2004). A review of the enzymology of arsenic metabolism and a new potential role of hydrogen peroxide in the detoxication of the trivalent arsenic species. Toxicol. Appl. Pharmacol. 198:327-335.

Bartlett RJ (1988). Mobility and Bioavailability of Chromium in Soils. Adv. Environ. Sci. Technol. 20:267-304.

Bartlett RJ, James B (1983). Behavior of Chromium in Soils: VII. Adsorption and Reduction of Hexavalent Forms. J. Environ. Qual. 12(2):177-181.

Begun A, Ramaiah M, Harikrishna, Khan I, Veena K, (2009). Analysis of Heavy Metals Concentration in Soil and Litchens from Various Localities of Hosur Road, Bangalore, India. E-J. Chem. 6(1):13-22. www.e-journals.net

Benbrahim-Tallaa L, Waalkes MP (2008). Inorganic arsenic and human prostate cancer. Environ. Health Perspect. 116:158-164.

Celik I, Gallicchio L, Boyd K, Lam TK, Matanoski G, Tao X (2008). Arsenic in drinking water and lung cancer: A systematic review. Environ. Res. 108:48-55.

Chen CJ, Chiou HY, Chiang MH, Lin LJ, Tai TY (1996). Dose-response relationship between ischemic heart disease mortality and long-term arsenic exposure. Arterioscler. Thromb. Vasc. Biol. 16:504-510.

Chen CJ, Wu MM, Lee SS, Wang JD, Cheng SH, Wu HY (1988). Atherogenicity and carcinogenicity of high-arsenic artesian well water. Multiple risk factors and related malignant neoplasms of blackfoot disease. Arteriosclerosis 8:452-460.

Chirenje T, Ma L, Reeves M, Szulczewski M (2004). Lead Distribution in Near-Surface Soils of Two Florida Cities: Gainesville and Miami. Geoderma 119:113-120.

Chiu HF, Ho SC, Wang LY, Wu TN, Yang CY (2004). Does arsenic exposure increase the risk for liver cancer? J. Toxicol. Environ. Health A 67:1491-1500.

de La Calle Guntinas MB, Semeraro A, Wysocka I, Cordeiro F, Quetel C, Emteborg H, Charoud-Got J, Linsinger TPJ (2011). Proficiency test for the determination of heavy metals in mineral feed.The importance of correctly selecting the certified reference materials during method validation. Food Addit. Contam. Part A Chem. Anal. Control Exposure Risk Assess. 28(11):1534-1546.

Eckel H (2005). Assessment and Reduction of Heavy Metal Input Into Agro-Ecosystems: Final Report of the EU-Concerted Action AROMIS. Münster, Westf: Landwirtschaftsverl. Münster.

Finley JW (2004). Does Environmental Exposure to manganese pose a health risk to healthy adults? Nutr. Rev. 62:148-153.

Garelick H, Jones H, Dybowska A, Valsami-Jones E (2008). Arsenic pollution sources. Rev. Environ. Contam. Toxicol. 197:17-60.

Gerber P, Chilonda P, Franceschini G, Menzi H (2005). Geographical determinants and environmental implications of livestock production intensification in Asia. Bioresour. Technol. 96:263-276.

Ghosh M, Singh SP (2005). Comparative Uptake and Phytoextraction Study of Soil Induced Chromium by Accumulator and High Biomass weed Species. Appl. Ecol. Environ. Res. 3(2):67-79. www.ecology.kee.hu.

Gong G, O'Bryant SE (2010). The arsenic exposure hypothesis for Alzheimer disease. Alzheimer Dis. Assoc. Disord. 24:311-316.

Gong G, O'Bryant SE (2012). Low-level arsenic exposure, AS3MT gene polymorphism and cardiovascular diseases in rural Texas counties. Environ. Res. 113(2012):52-57.

Goyer RA, Clarkson TW (2001). Toxic Effects of Metals. In, Casarett and Doullis Toxicology: The basic science of poisons, Sixth Edition (C.D. Klaassen, ed.) Mc-Graw-Hill, New York, pp. 811-867.

Jomova K, Jenisova Z, Feszterova M, Baros S, Liska J, Hudecova D, Rhodes CJ, Valko M (2011). Arsenic: Toxicity, oxidative stress and human disease. J. Appl. Toxicol. 31:95-107.

Kobayashi J (1978). Pollution by cadmium and the itai-itai disease in Japan. In: Toxicity of heavy metals in the environment. Oehme FW (ed.) Marcel Dekker Inc, New York, pp. 199-260.

Lenntech WT (2009). Chemical Properties, Health and Environmental Effects of Copper. Lenntech Water Treatment and Purification Holding B.V. www.lenntech.com/periodic/elements/cu.htm.

Li Y-X, Li W, Wu J, Xu LC, Su QH, Xiong X (2007). Contribution of additives Cu to its accumulation in pig faeces: Study in Beijing and Fuxin of China. J. Environ. Sci. (China) 19:610-615.

Liao CM, Shen HH, Chen CL, Hsu LI, Lin TL, Chen SC, Chen CJ (2009). Risk assessment of arsenic-induced internal cancer at long-term low dose exposure. J. Hazard. Mater. 165:652-663.

Mench M, Didier V, Löffler M, Gomez A, Masson P (1994). A Mimicked *in-situ* Remediation Study of Metal-contaminated Soils with emphasis

Mink PJ, Alexander DD, Barraj LM, Kelsh MA, Tsuji JS (2008). Low level arsenic exposure in drinking water and bladder cancer: A review and meta-analysis. Regul. Toxicol. Pharmacol. 52:299-310.

National Population Commission, NPC (2009). Federal Republic of Nigeria Official Gazette. 96:2, Abuja, 2nd February.

National Research Council Subcommittee (2001). Arsenic in drinking water Report. Committee on Toxicology, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies. Arsenic in Drinking Water, 2001 update. Washington, D.C. National Academy Press.

Nicholson FA, Chambers BJ, Williams JR, Unwin RJ, (1999). Heavy metal contents of livestock feeds and animal manures in England and Wales. Bioresour. Technol. 70:23-31.

Nogawa K, Honda R, Kido T, Tsuritani I, Yamanda Y (1987). Limits to protect people eating cadmium in rice, based on epidemiological studies. Trace Subst. Environ. Health 21:431-439.
on Cadmium and Lead. J. Environ. Qual. 23:58-63.

Rahman MM, Ng JC, Naidu R (2009). Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. Environ. Geochem. Health 31(Suppl. 1):189-200.

Reyes-Gutiérrez LR, Romero-Guzmán ET, Cabral-Prieto A, Rodríguez-Castillo R (2007). Characterization of Chromium in Contaminated Soil Studied by SEM, EDS, XRD and Mössbauer Spectroscopy. J. Miner. Mater. Character. Eng. 7(1):59-70.

Shi G, Chen Z, Bi C, Wang L, Teng J, Li Y, Xu S (2011). A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. Atmos. Environ. 45:764-771.

Smith AH, Lopipero PA, Bates MN, Steinmaus CM, (2002). Arsenic epidemiology and drinking water standards. Sci. 296:2145-2146.

Stredrick DL, Stokes AH, Worst TJ, Freeman WM, Johnson EA, Lash LH, Vahter M, Berglund M, Akesson A, Liden C (2002). Metals and Women's Health. Environ. Res. 88:145-155.

Tseng CH, Chong CK, Tseng CP, Hsueh YM, Chiou HY, Tseng CC (2003). Long-term arsenic exposure and ischemic heart disease in arseniasis- hyperendemic villages in Taiwan. Toxicol. Lett. 137:15-21.

United States Department of Agriculture, USDA (2000). Heavy metals contamination. Soil Quality Urban Technical Note 3, Natural Resources Conservation Service.

United States Environmental Protection Agency, USEPA (2004). Drinking water health advisory for manganese. US Environmental Protection Agency Office of Water (4304T) Health and Ecological Criteria Division Washington, DC 20460. Available online at http://www.epa.gov/safewater/EPA-822-R-04-003 January, Accessed April 11, 2013.

Vahidnia A, vander Voet GB, deWolff FA (2007). Arsenic neurotoxicity - A review. Hum. Exp. Toxicol. 26:823-832.

Valko M, Morris H, Cronin MTD (2005). Metals, toxicity and oxidative stress. Curr. Med. Chem. 12: 1161-1208.

Wisconsin Department of Health and Family Services, WDHFS (2007). manganese in drinking water. Information for home owners and other members of the public. Human Health Hazards. Available online at www.dhfs.wisconsin.gov/eh

World Health Organization, WHO (2004a). Guidelines for drinking water quality, Third Edition. Volume 1: Recommendations. World Health Organization, Geneva.

World Health Organization, WHO (2004b). Manganese in drinking water. Background document for development of WHO Guidelines for Drinking water Quality. World Health Organization, Geneva, Switzerland.

World Health Organization, WHO (2004c). Iron in drinking water. Background document for development of WHO Guidelines for Drinking Water Quality. World Health Organization, Geneva, Switzerland.

Wyszkowska J (2002). Soil contamination by chromium and its enzymatic activity and yielding. Pol. J. Environ. Stud. 11(1):79-84.


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