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Review

A review of heavy metals in soil and aquatic systems of urban and semi-urban areas in Malawi with comparisons to other selected countries

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Growth of cities in developing countries comes with increasing transportation and industrial activities which may contribute to accumulation of heavy metals in the environment. This paper provides a review of studies on heavy metals in Malawi`s environment, their potential environmental impacts and possible removal methods with comparisons to other selected countries. The reviewed data from Malawi showed that in water samples, heavy metal concentrations were higher than World Health Organisation (WHO) and Malawi Bureau of Standards (MBS) safe limits especially in streams passing through industrial sites. Reports of heavy metals (especially Cu, Mn and Zn) showed that in industrial effluents, the individual levels of each of them were at least 6 times higher as compared to those in surface water bodies. In rivers there was accumulation of heavy metals (Cu, Cd, Cr, Fe, Mn, Pb, Ni and Zn) by algae whereby bioconcentration factors (BCF) ranged from 1.0 to 42 in some of the studies. Generally, metal levels in soils and selected organisms were much higher than those in water samples which further confirm possible accumulation. Since some aquatic organisms are consumed by humans, there is potential for the heavy metals to cause cancer and kidney damage. The studies done in Malawi compared well to those conducted elsewhere. The degradation of water resources by heavy metals compromises sustainability of water bodies and vital aquatic ecosystems hence negatively impacting on Integrated Water Resource Management (IWRM) efforts. This calls for periodic heavy metal monitoring and identifying ways of reducing their release into the environment.

Key words: Environment, heavy metals, pollution, public health, Malawi.

INTRODUCTION

Heavy metal pollution is a serious problem worldwide especially in areas with high anthropogenic pressures (Yeh et al., 2009; Nagajyoti et al., 2010). Heavy metals are toxic, resist degradation and tend to accumulate in organisms and also the environment (Ahmad et al., 2010; Abbas et al., 2014). In urban environment, the concentration of heavy metals tends to be higher than background levels especially in areas close to large industrial complexes (Sun et al., 2010; Wei and Yang, 2010) which could potentially pollute the environment especially soils and aquatic systems. In polluted aquatic ecosystems the transfer of metals through food chains can be high enough to bring about harmful concentrations in the tissues of aquatic organisms (Dallinger et al., 1987).The accumulation of metals in organisms in the environment is highly dependent on their availability for uptake by the organisms (Janssen et al., 1997), hence leads to health hazards on humans and wildlife (Li and Zhang, 2010). The health hazards of heavy metals include cancer, damage of internal organs and interference with vital systems of the body of organisms. Dietary exposure to heavy metals through the food chain is a risk to the health and wellbeing of organisms (Davies et al., 2006; Kachenko and Singh, 2006; Yi et al., 2011). In the environment, heavy metals have been implicated in the reduction of species diversity and population densities of organisms as was the case with freshwater mussels in North America (Naimo, 1995). Although all heavy metals have the potential to cause problems, however the main threats to human health are associated with exposure to lead, cadmium, mercury and arsenic (Jarup, 2003).

The release of heavy metals in the environment can be through industrial and household waste discharges, agricultural and mining activities (Akcay et al., 2003; Wuana and Okieimen, 2011; Zeitoun and Mehana, 2014). According to Clements et al. (2000), mining activities contribute to significant heavy metal pollution of streams as is the case in the Rocky Mountains (USA). In rivers, the concentration of heavy metals tends to be higher downstream mostly due to agricultural activities, industrial effluents and anthropogenic wastes (Begum et al., 2009). Generally, more than 90% of the heavy metal load is bound to particulates like suspended matter and sediments (Calmano et al., 1993). In soil solution, heavy metals can form hydrolysis species and complexes with inorganic ligands such as Cl^- and SO_4^{2-}. The importance of the hydrolysis species and inorganic complexes depends on pH and the concentration of metal and ligands (Weng et al., 2002). In urban environments, motor vehicles through emissions and tyre wear can also contribute to heavy metal pollution (Brown and Peake, 2006). This is in addition to run-off from informal settlements and industries which can contribute significant levels of heavy metals in surface water bodies (Binning and Baird, 2001).

The fact that heavy metals cause environmental problems and also they can come from multiple sources, calls for continuous studies of these environmental contaminants. In Malawi a number of studies have been conducted to determine the concentrations of heavy metals in different environments such as soils, aquatic organisms and aquatic environments such as streams, rivers, lakes and ponds among others. However, appraisal of data from such studies has been either scanty or insignificant. It is imperative to have meaningful understanding and assessment of heavy metal pollution in Malawi to ensure sustainable management of water resources and the environment in general. In this paper therefore, a review of heavy metal studies in soil and aquatic systems of urban and semi-urban areas of Malawi is provided. Furthermore heavy metal concentrations in environmental samples are compared to studies conducted elsewhere. The paper also provides recommendations on possible remediation methods based on the evaluated studies conducted in the same area.

THE STUDY AREA

This study desk reviewed data on heavy metals conducted in soil and aquatic systems of urban and semi-urban areas of Malawi (13.25°S, 34.30°E). Malawi is a landlocked country bordered by Mozambique to the east, south and west, Tanzania to the northeast and Zambia to the northwest. It has an estimated population of 16 million people. The major cities are: Blantyre (commercial city), Lilongwe (capital city), Mzuzu (only city in the north) and Zomba (old capital city) (Figure 1). Malawi`s economy is characterized by a high dependence on agriculture, a narrow industrial base and weak intersectoral linkages (FAO, Food and Agricultural Organization, 2003).

HEAVY METAL ANALYSIS METHODS

Analysis of heavy metals and trace elements in drinking water, sediment, soil, solid wastes and several other types of samples are performed using various methods and equipment. These heavy and trace elements include calcium (Ca), magnesium (Mg), Iron (Fe), potassium (K), sodium (Na), lead (Pb), zinc (Zn), copper (Cu), cobalt (Co), cadmium (Cd), nickel (Ni), chromium (Cr), molybdenum (Mo), arsenic (As) and manganese (Mn) (APHA, American Public Health Association, 1998).

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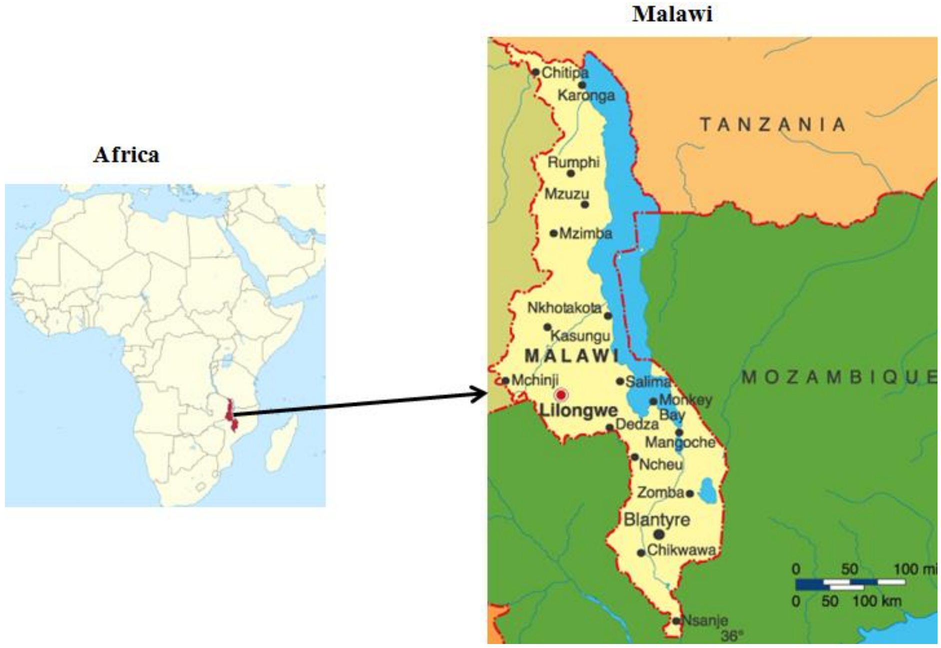

Figure 1. Map of Malawi showing cities and some major towns.

Instrumental analysis methods like *Atomic Absorption Spectrometry* (AAS), *Inductively Coupled Plasma-Mass Spectrometry* (ICP-MS), *Inductively Coupled Plasma-Atomic Emission Spectrometry* (ICP-AES), and *Inductively Coupled Plasma- Optical Emission Spectrometry* (ICP-OES) are commonly used for the determination of heavy metals in environmental samples (APHA, 1998; US-EPA, United States Environmental Protection Agency, 2000). Several factors are considered when selecting the type of method and instrument for analysis of heavy metals and trace elements. These factors include sample type, sample processing, instrument sensitivity or detection limit, sample throughput, matrices or spectral interference, concentration range, ruggedness, regulation requirements, time and cost (APHA, 1998). On one hand, the atomic spectrometry instruments (such as Flame *Atomic Absorption Spectrometry*-FAAS or *Graphite Furnace Atomic Absorption Spectrometry*-GFAAS) are the most common and reliable techniques for trace metal and metalloids analysis in environmental samples. On the other hand, the ICP-MS and ICP-OES are suitable for trace-metal content analysis in water and wastewater samples. In cases where maximum detection is essential, the ICP-MS method is preferable. The ICP-OES is more rugged such that it can easily analyze samples with higher total dissolved solids (TDS) content. However, elements like lead (Pb) and arsenic (As) are well analyzed using ICP-MS because of their low regulatory limit in drinking water (US-EPA, 2000). Acid digestion (acid or acid mixtures) are often employed to ensure metal elements are totally dissolved in liquid or leached from solid samples. To ensure best digestion results and minimum (spectral) interferences, selection of acids or acid mixture is paramount and this is also dependent on the analyte of interest to be analyzed among other factors (APHA, 1998; US-EPA, 2000). The US-EPA 2007 and 2008 methods are often used for water sample preparation and analysis while 3050B, 3051A, and 3052 methods (total digestion) are used for preparation and analysis of soils, solid waste and sludge samples (APHA, 1998; US-EPA, 1994, 1992). Trace elements and metals in solution are readily measured by flame (direct aspiration) AAS, a simple and rapid method applicable to a variety of environmental samples (water, industrial wastes, soils, sludge and sediments) This may be achieved by following a revised method 7000B (SW-846) by US-EPA (US-EPA, 2007). The EPA 2007 method may be used for multi-elemental and some non-metal analyses in solution using ICP-AES. The method is considered a consolidation of prevailing methods for water, wastewater, and solid wastes (US-EPA, 1994, 1992). The revised method 3050B by US-EPA (1996) is used for acid digestion of sediments, sludges, and soils. The method gives two distinct procedures for preparation of sediments, sludge and soil samples for heavy metals and trace element analysis by FLAA or ICP-AES and by GFAA or ICP-MS. Similarly, the US-EPA (1998) method 6020A describes the multi-elemental determination of analytes by ICP-MS in environmental samples including

Table 1. International and national drinking water standards for trace elements and heavy metals.

Parameter (mg/L)	WHO (2011)	US-EPA (2012)		MBS (2005)
		MCL (P)	MCL (S)	
Na^+	NA. *200	NA	30-60	100-200
K^+	NA			25-50
Mg^{2+}	NA	NA	NA	30-70
Ca^{2+}	*100-300	NA	NA	80-150
Fe^{3+}	NA	NA	0.30	0.01-0.20
Cu^{2+}	2.00	1.3	1.0	0.5-1.0
Zn^{2+}	Nh	NA	5.0	3.0-5.0
Pb^{2+}	0.01 (A, T)	0.015 (lead action level)	NA	0.01-0.05
Cr^{3+}	0.05 (P)	0.10	NA	0.005-0.010
Ni^{2+}	0.07	NA	NA	0.05-0.15
Mn^{2+}	0.40	NA	0.05	0.05-0.10
Cd^{2+}	0.003	0.005	NA	0.003-0.005
As	0.01 (A, T)	0.01	NA	
Hg	0.006	0.002	NA	
Ba	0.7	2.0	NA	
Al	0.90 (health-based value)	NA	0.05-0.20	

MCL maximum contaminant levels. (P): Primary which refers to health-related effects; (S): Cosmetic (skin or tooth discoloration) or aesthetic (taste, odor or color) effects. Nh: Not of health concern at levels found in drinking water. NA: Data not available. *taste threshold value. A, T: Provisional guideline value.

water and waste extracts or digests. The revised method 6010C, in contrast, is applicable for analysis of trace elements in solution using ICP-AES (US-EPA, 2000).

For protection of the environment, animal and human health and other species, stringent guidelines and regulations have been set in Europe, Japan, United States (US) and in many other countries around the world that call for greater precision in heavy metal and trace elements analysis (US-EPA, 1996; WHO, 2008). Regulatory bodies such as World Health Organization (WHO) and United States Environmental Protection Agency (US-EPA) set maximum contaminant levels (MCL) for various heavy metals and trace elements in drinking water sources. In Malawi, the maximum and allowable levels of contaminants in drinking water are set by the government institutions namely Malawi Standards Board and Malawi Bureau of Standards (MBS). Table 1 shows standards of selected heavy metals in drinking water by WHO (2011), US-EPA (2012) and MBS (2005).

HEAVY METAL STUDIES IN MALAWI

Studies in surface water samples

Table 2 show results of heavy metal studies conducted in Malawi and worldwide. In Malawi, Kaonga et al. (2008) assessed Cd, Mn and Pb in Blantyre City streams. These streams pass through industrial areas and also they are frequent recipients of raw sewage by virtue of broken sewer lines apart from farming activities taking place along their banks. The data show that Cd levels (0.07 to 0.111 mg/L) reported by Kaonga et al. (2008) were higher than those reported elsewhere. However, Mn (n.d-0.626 mg/L) and Pb (0.011 to 0.23 mg/L) concentrations found in the same study were within the range of similar environments reported elsewhere. In the same area, Kaonga et al. (2012) reported that concentrations of Cu, Fe, Zn, Cr and Ni were within the range reported elsewhere (Tables 1 and 2). Furthermore, these results, compared well with studies done in the same area by Sajidu et al. (2006) and Kumwenda et al. (2012). Another study done in Malawi by Chidya et al. (2011) on Likangala River, Zomba City reported maximum concentrations of Cd (0.05 mg/L) and Pb (0.71 mg/L) to be higher than those from other countries. However the values found for these analytes were lower than those found in Blantyre City as reported by Kaonga et al. (2008) and Kaonga et al. (2012). This is due to the fact that Blantyre City is a commercial and industrial capital of Malawi hence more activities which could lead to stream pollution. The sources of Cd in Blantyre City were mainly attributed to metal processing operations, phosphate fertilizers and deposition of metal products. It was also noted in the studies done in Blantyre City that in the dry season, the concentrations of heavy metals were generally higher than in the rainy season which was mainly attributed to dilution. On the other hand, a study

Table 2. Cd, Cr, Cu, Fe, Mn, Pb, Ni and Zn in surface water in Malawi as compared to other countries.

Metal	Conc. (ppm)	Area	Author
Cadmium	0.0001-0.001	Greece	Simeonov et al., 2003
	n.d-0.0013	Turkey	Turgut, 2003
	n.d	India	Singh et al., 2005
	n.d-0.015	Malawi	Sajidu et al., 2006
	n.d-0.00049	Turkey	Demirak et al., 2006
	n.d-0.01	Turkey	Karadede-Akin and Unlu, 2007
	0.07-0.111	Malawi	Kaonga et al., 2008
	0.001-0.003	India	Kar et al., 2008
	n.d-0.00004	Greece	Papafilippaki et al., 2008
	0.0024-0.0241	India	Suthar et al., 2009
	0.007-0.012	Bangladesh	Ahmad et al., 2010
	0.0003-0.006	China	Li and Zhang, 2010
	0.0004-0.04	India	Reza and Singh, 2010
	n.d-0.05	Malawi	Chidya et al., 2011
	n.d-0.02	Malawi	Kumwenda et al., 2012
	n.d-0.049	Malawi	Msika et al., 2014
Chromium	0.011-0.028	Turkey	Akcay et al., 2003
	0.001-0.018	Greece	Simeonov et al., 2003
	n.d-0.0026	Turkey	Turgut, 2003
	0.0007-0.1183	Iran	Diagomanolin et al., 2004
	0.001-0.0057	India	Singh et al., 2005
	0.013-0.479	Malawi	Sajidu et al., 2006
	n.d-0.0004	Turkey	Demirak et al., 2006
	0.001-0.044	India	Kar et al., 2008
	n.d-0.32	India	Begum et al., 2009
	0.0312-0.3309	Iran	Suthar et al., 2009
	0.489-0.645	Bangladesh	Ahmad et al., 2010
	0.001-0.005	Greece	Papafilippaki et al., 2008
	n.d-0.39	Malawi	Chidya et al., 2011
	n.d-0.419	Malawi	Kaonga et al., 2012
	0.10-0.46	Malawi	Kumwenda et al., 2012
Copper	0.010-0.013	Turkey	Akcay et al., 2003
	0.002-0.007	Greece	Simeonov et al., 2003
	n.d-0.01668	Turkey	Turgut, 2003
	0.0005-0.0703	Iran	Diagomanolin et al., 2004
	n.d	India	Singh et al., 2005
	0.010-0.046	Malawi	Sajidu et al., 2006
	n.d-0.0013	Turkey	Demirak et al., 2006
	0.011-1.3	Turkey	Karadede-Akin and Unlu, 2007
	0.003-0.032	India	Kar et al., 2008
	0.001-0.013	Greece	Papafilippaki et al., 2008
	0.00024-0.0016	Turkey	Kucuksezgin et al., 2008
	0.0024-0.0027	China	Yi et al., 2008
	0.03-1.12	India	Begum et al., 2009
	n.d-4.3725	India	Suthar et al., 2009
	0.107-0.201	Bangladesh	Ahmad et al., 2010
	n.d-0.046	China	Li and Zhang, 2010

Table 2. Cont'd.

	0.001-0.0047	India	Reza and Singh, 2010
	n.d	Malawi	Chidya et al., 2011
	n.d-0.076	Malawi	Kaonga et al., 2012
	0.04-0.12	Malawi	Kumwenda et al., 2012
Iron	0.113-0.833	Greece	Simeonov et al., 2003
	0.034–0.117	India	Singh et al., 2005
	0.837-7.280	Malawi	Sajidu et al., 2006
	0.08-1.98	Malawi	Chavula and Mulwafu, 2007
	n.d-5	Turkey	Karadede-Akin and Unlu, 2007
	0.025-5.49	India	Kar et al., 2008
	0.0013-0.687	Turkey	Kucuksezgin et al., 2008
	n.d-1.2474	India	Suthar et al., 2009
	n.d-0.086	China	Li and Zhang, 2010
	0.005-0.095	India	Reza and Singh, 2010
	n.d-10.25	Malawi	Chidya et al., 2011
	n.d-3.209	Malawi	Kaonga et al., 2012
	n.d-27.23	Malawi	Msika et al., 2014
Manganese	0.050-0.098	Turkey	Akcay et al., 2003
	0.045-0.291	Greece	Simeonov et al., 2003
	0.0013-0.0053	India	Singh et al., 2005
	0.045-0.747	Malawi	Sajidu et al., 2006
	n.d-3	Turkey	Karadede-Akin and Unlu, 2007
	n.d-0.626	Malawi	Kaonga et al., 2008
	0.025-2.72	India	Kar et al., 2008
	0.03-0.17	Turkey	Kucuksezgin et al., 2008
	n.d-1.25	India	Begum et al., 2009
	0.0017-0.8675	India	Suthar et al., 2009
	0.015-0.085	China	Li and Zhang, 2010
	0.0015-0.102	India	Reza and Singh, 2010
	n.d-2.73	Malawi	Chidya et al., 2011
Nickel	0.009-0.013	Turkey	Akcay et al., 2003
	0.002-0.012	Greece	Simeonov et al., 2003
	0.00149-0.01075	Turkey	Turgut, 2003
	0.041-0.1107	Iran	Diagomanolin et al., 2004
	0.009-0.017	India	Singh et al., 2005
	0.123-0.338	Malawi	Sajidu et al., 2006
	0.01-0.4	Turkey	Karadede-Akin and Unlu, 2007
	0.012-0.375	India	Kar et al., 2008
	0.00039-0.009	Turkey	Kucuksezgin et al., 2008
	0.05-5.25	India	Begum et al., 2009
	0.007-0.010	Bangladesh	Ahmad et al., 2010
	0.0001-0.006	China	Li and Zhang, 2010
	0.009-0.052	India	Reza and Singh, 2010
	n.d	Malawi	Chidya et al., 2011
	0.101-0.578	Malawi	Kaonga et al., 2012
Lead	0.020-0.048	Turkey	Akcay et al., 2003

Table 2. Cont'd.

	n.d-0.00313	Turkey	Turgut, 2003
	0.019-0.039	India	Singh et al., 2005
	n.d-0.116	Malawi	Sajidu et al., 2006
	n.d-0.0007	Turkey	Demirak et al., 2006
	n.d-0.05	Turkey	Karadede-Akin and Unlu, 2007
	0.011-0.23	Malawi	Kaonga et al., 2008
	0.001-0.250	India	Kar et al., 2008
	0.00059-0.0015	Turkey	Kucuksezgin et al., 2008
	n.d-0.013	Greece	Papafilippaki et al., 2008
	0.0301-0.9021	India	Suthar et al., 2009
	0.058-0.072	Bangladesh	Ahmad et al., 2010
	0.08-9.95	India	Begum et al., 2010
	n.d–0.026	China	Li and Zhang, 2010
	0.01-0.027	India	Reza and Singh, 2010
	n.d-0.71	Malawi	Chidya et al., 2011
	0.21-0.93	Malawi	Kumwenda et al., 2012
	0053-0.080	Turkey	Akcay et al., 2003
	0.020-0.157	Greece	Simeonov et al., 2003
	n.d-0.29392	Turkey	Turgut, 2003
	0.011-0.032	India	Singh et al., 2005
	0.123-0.630	Malawi	Sajidu et al., 2006
	n.d-0.0022	Turkey	Demirak et al., 2006
	0.04-5	Turkey	Karadede-Akin and Unlu, 2007
	0.012-0.37	India	Kar et al., 2008
Zinc	0.00019-0.0029	Turkey	Kucuksezgin et al., 2008
	n.d-0.142	Greece	Papafilippaki et al., 2008
	<0.001-0.0021	China	Yi et al., 2008
	0.000501-0.8364	India	Suthar et al., 2009
	n.d–10.70	India	Begum et al., 2010
	0.0004-0.0801	India	Reza and Singh, 2010
	n.d-0.14	Malawi	Chidya et al., 2011
	0.102-2.614	Malawi	Kaonga et al., 2012
	0.05-0.18	Malawi	Kumwenda et al., 2012

n.d: not detected.

done on water from geothermal springs in Nkhata Bay District, Northern Malawi by Msika et al. (2014) found the concentration of Fe (≤27.23 mg/L) to be higher than that found in surface water bodies in Malawi as shown in Table 2. Some of the geothermal spring samples had Fe concentration higher than WHO and MBS safe limits (Fe, 0.20 mg/L). However the concentration of Cd was within the range of that found in streams of Malawi. A study by Branchu et al. (2010) detected heavy metals at nanomolar concentration in Lake Malawi (Africa's second largest lake). It was noted in this study that the lake annual chemical budget showed that the northern watershed generates the main elemental input to the lake. The northern watershed of Lake Malawi is hilly and there are some mines (coal and uranium) which could potentially be contributing to heavy metals into the lake. Lake Malawi lies in a region of savanna and a sub-tropical forest (Brown et al., 2000). There was also a study by Chavula and Mulwafu (2010) in Likangala River catchment, Zomba, Malawi in which they detected Fe (0.08-1.98 mg/L). It was noted that this concentration of Fe did not pose any threat to human beings based on comparisons between this study and standards.

The heavy metal concentrations found in Malawi were comparable to those found elsewhere as indicated in Table 2. The highest concentrations of heavy metals recorded in water samples both in Malawi and elsewhere were for Fe. The sources of this metal are varied and include iron rich mineral soils and also industrial inputs. Also the issue of having streams that pass through industrial areas being polluted by heavy metals is not peculiar to Blantyre City alone. For example, a study done in India by Gaur et al. (2005), found that the River Gomti became highly polluted after passing through the city of Lucknow where it received industrial and domestic wastes through mainly drainage systems. The degradation of water resources by heavy metals in Malawi and other countries compromises sustainability of water bodies and vital aquatic ecosystems, hence negatively impacting Integrated Water Resource Management (IWRM) efforts.

Studies in industrial effluent

A study was conducted on effluent from a match stick factory in Blantyre, Malawi by Schutz (2013). In this study the concentration ranges were: 13.5 to 33.33 mg/L Cr, 438-3693 mg/L K and 7-3450 mg/L Zn. The concentrations of Cr and Zn exceeded the tolerance limits (0.05 mg/L Cr and 5 mg/L Zn) set by Malawi Bureau of Standards for wastewater.

Kuyeli (2007) analysed industrial effluents in Blantyre city, Malawi. In this study, the concentration ranges of heavy metals in industrial effluents were as follows: 0.002-0.005 mg/L Cd, 17.81-56.12 mg/L Cr, 0.026-2 mg/L Cu, 0.074-14.08 mg/L Fe, 0.001-9.01 mg/L Mn, 0.143-2.6 Pb, 0.07-1.11 Ni and 0.01-30.83 mg/L Zn. The concentration of heavy metals found in industrial effluents in this study, were at least six times higher than the corresponding levels in surface water bodies (streams) in the same area. It was generally observed that the effluents from industries in Blantyre City have a high potential of polluting surface water bodies and if they are not properly managed by good wastewater treatment systems, they could result in gross impairment of water quality of streams in Blantyre City.

Heavy metal studies in soils

A study by Kaonga and Monjerezi (2012) in river bank soils along streams that pass through industrial areas in Blantyre, Malawi, reported maximum concentrations of heavy metals to be as follows: Cd 0.18 mg/kg dw, Cr 8.19 mg/kg dw, Cu 10.13 mg/kg dw, Fe 82.82 mg/kg dw, Mn 31.43 mg/kg dw, Ni 4.32 mg/kg dw, Pb 3.49 mg/kg dw and Zn 17.45 mg/kg dw. In same study, the concentration of the heavy metals in soils was higher in dry season than in rainy season. This was attributed to the dilution effect. There are no established standards for heavy metals in soils in Malawi however a comparison with standards from other countries indicated that these values were lower than the maximum permissible limits of Europe and Canada (Bohn et al., 1979; Alloway and Ayres, 1997).

Lakudzala and Khonje (2011) found traces of Pb from soil sampled in Blantyre and also the ones bought in Indian shops (Indian soils). These soils are consumed by mostly pregnant women. The Pb concentration in this study ranged from 0.05 to 0.07 mg/g dw. The concentration of Pb in Indian soils was higher than that of Blantyre soils however both soils pose a health hazard to individuals who consume them.

In Zomba City, Malawi a study by Orvestedt (2015) on dumpsite soils, found the following ranges of heavy metals: 4-10 mg/kg dw Cd, 5 to 69 mg/kg dw Cu, 14700 to 17600 mg/kg dw Fe and 130 to 210 mg/kg dw Zn. In this study, the values found were compared to the Swedish Environmental Protection guideline values of 2009. The concentration of Cd exceeded these guideline values (0.5 mg/kg). This poses a potential danger to human health since the areas close to dumpsites are used for growing crops.

A study by Braun (2015) on agricultural soils close to a dumpsite and wastewater treatment facility in Zomba City, Malawi found the following concentration of heavy metals: 4-11 mg/kg dw Cd, 5-69 mg/kg dw Cu, 14693-17592 mg/kg dw Fe and 183 to 231 mg/kg dw Pb. In this study, it was noted that the concentrations of Pb were much higher than expected as such this study called for a more detailed risk assessment of the metals in the area.

Pollution of soils by heavy metals is a worldwide problem (Tandy et al., 2004) with reports available in several countries. According to Wei and Yang (2010), heavy metal pollution in urban areas of China has become serious with rapid industrialization during the last two decades. This is supported by a study done by Khan et al. (2008) in Beijin who found that irrigating crops with wastewater caused significant contamination of soils by heavy metals. A study by Guo et al. (2012) in Yibin City, Sichuan Province, China found that the concentration of heavy metals (As, Cu, Pb and Zn) were higher in the vicinity of industrial areas as compared to parks. A study by Jung and Thornton (1996) found high concentrations of Cd, Cu, Pb and Zn in the vicinity of a Pb-Zn mine as compared to uncultivated sites, household garden sites and control sites. In Italy (Naples city), a study by Imperato et al. (2003) found that many surface soils from the urban area as well as from the eastern industrial district contained levels of Cu, Pb and Zn that largely exceeded the limits (120, 100 and 150 mg kg1 for Cu, Pb and Zn, respectively) set for soils of public, residential and private areas by the Italian Ministry of Environment. Also a study done by Kalbitz and Wennrich (1998) in wetland soils of the Mulde River in the industrial district of Bitterfeld-Wolfen (Germany) found concentrations of up to 1100 mg kg^{-1} for Zn, 800 mg kg^{-1} for Cr and 364 mg kg^{-}

^{1} for Cu. It was further revealed in this study that there was heavy metal translocation from top to bottom soils. This may potentially pose as a threat to ground water resources. In another study done in Damascus, Syria by Moller et al. (2005), it was found that Cr concentrations of up to 1800 mg kg^{-1} were found near a tannery industrial estate. In a study conducted by Manta et al. (2002) on urban top soil in Palermo (Sicily), Italy the ranges of heavy metals found were as follows; 10 to 344 mg kg^{-1} Cu, 0.27 to 3.8 mg kg^{-1} Cd, 12 to 100 mg kg^{-1} Cr, 57 to 2516 mg kg^{-1} Pb, 142 to 1259 mg kg^{-1} Mn, 7 to 38.6 mg kg^{-1} Ni and 52 to 433 mg kg^{-1} Zn. It was noted in this study that vehicular traffic was the main contributor of heavy metal pollution in this urban area. Another study that noted the contribution of vehicular traffic to heavy metal pollution was that done by Jaradat and Momani (1999) on a major highway connecting Amman with the Southern parts of Jordan. In that study, the concentrations of Cu, Cd, Pb and Zn were 29.7, 0.75, 188.8 and 121.7 µg g^{-1}, respectively 1.5 m east of the highway. It was further noted that the concentrations of the heavy metals dropped to background levels 60 m from the highway. Also Chen et al. (2005) in a study on 30 urban parks in China found that the maximum concentrations of Cu, Ni, Pb and Zn were 457.5, 37.2, 207.5 and 196.9 mg kg^{-1}, respectively. Further review of these concentrations pointed to the fact that they were contributed by vehicle traffic saves for Ni which was based on background levels. Anthropogenic activities can have a significant contribution to heavy metal pollution in soils as was seen in a study done by Chen et al. (1997) in Hong Kong. In that study, it was noted that while the concentrations of Cd, Cu, Pb and Zn in a forest (Country Park) were 0.697, 11.7, 45.7 and 44.6 µg g^{-1}, respectively; those of Cd, Cu, Pb and Zn in an industrial area were 1.31, 26.1, 87.7 and 62.8 µg g^{-1}, respectively. According to Sun et al. (2010), the modernization of industry and the presence of intensive human activities in urban areas have exacerbated the problem of heavy metal contamination in soils. This is because soils serve as both sinks and sources of heavy metal contaminants in the terrestrial environment. Excessive accumulation of heavy metals in urban soils may result not only in heavy metal contamination of the soils but also an increased exposure for human beings. In actual fact, the environmental risk of heavy metal pollution is pronounced in soils adjacent to large industrial complexes (Wang et al., 2007) which in most cases are located in urban areas.

Also when wastewater is used to irrigate crops, heavy metals tend to accumulate in soils. This was noted in a study by Mapanda et al. (2005) who found that the heavy metal concentrations (mg $kg^{-}1$) in soils ranged from 7.0 to 145 for Cu, 14 to 228 for Zn, 0.5 to 3.4 for Cd,<0.01 to 21 for Ni, 33 to 225 for Cr and 4 to 59 for Pb. It was concluded that the use of wastewater in urban horticulture enriches soils with heavy metals to concentrations that may pose potential environmental and health risks in the long-term.

Other studies on heavy metals in Malawi

Kaonga et al. (2008) studied Cd, Mn and Pb in algae, *Spirogyra aequinoctialis* in Blantyre City streams, Malawi. The maximum reported concentrations were: 0.91 mg/kg dw Cd, 16.13 mg/kg dw Mn and 0.97 mg/kg dw Pb. In a related study, Kaonga and Monjerezi (2012) found that the maximum heavy metal concentrations in *S. aequinoctialis* in the same streams were: 0.66 mg/kg dw Cr, 2.30 mg/kg dw Cu, 96.64 mg/kg dw Fe, 0.42 mg/kg dw Ni and 6.19 mg/kg dw Zn. These studies noted that *S. aequinoctialis* accumulated heavy metals from water. The bioconcentration factors (BCF) ranged from 1 to 42. Also Kaonga and Monjerezi (2012) determined the concentration of heavy metals in earthworms (*Apporectodea icteria*) found along the streams of Blantyre City, Malawi. The maximum concentrations were: 9.62 mg/kg dw Mn, 0.55 mg/kg dw Cd, 0.92 mg/kg dw Cu, 63.73 mg/kg dw Fe, 5.27 mg/kg dw Zn, 0.80 mg/kg dw Pb, 0.03 mg/kg dw Cr and 0.93 mg/kg dw Ni. This study noted that it was only Cd that was accumulated by *A. icteria* from stream soils therefore this organism cannot be used as a biological indicator for general heavy metal pollution in soils.

In another study done in Blantyre City, Kaonga and Monjerezi (2012) reported the concentrations of heavy metals in sewage sludge and sludge worms (*Tubifex tubifex*) sampled at Zingwangwa Wastewater Treatment Plant. The maximum concentrations on dry weight basis (in sludge and (*T tubifex*)) were: 2.31 mg/kg (2.18 mg/kg) Cd, 120.1 mg/kg (4.7 mg/kg) Cu, 22.4 mg/kg (0.95 mg/kg) Pb, 2301 mg/kg (3.69 mg/kg) Mn, 361.5 mg/kg dw (82.2 mg/kg) Zn. This study noted that *T. tubifex* did not show the ability to accumulate heavy metals (attributed to its high defecation and metabolic rate) except for Cd hence cannot be used as a bioindicator for general heavy metal pollution in sludge.

Ngonda (2014) assessed Pb, Cd, Mn, Zn, Cr, Cu and Fe in medicinal plants (*Trichodesma zeylanicumm, Securidaca longepedunculata and Vernonia glabra*) sampled from Zomba City and Machinga districts. Although all the heavy metals were detected in this study, however it was only in *S. longepedunculata* that the concentration of Cr exceeded the World Health Organization (WHO) permissible limit (Cr, 2.76 ppm).

A study on the concentration of heavy metals in cabbages irrigated with reservoir and tap water by Mumba et al. (2008) found the range of concentration to be as follows; 1.01-0.16 mg/L Cd, n.d -0.12 mg/L Pb and 0.05-0.09 mg/L Cr. In the same study, the concentrations of heavy metals irrigated with reservoir and tap water were; 0.71-1.25 mg/L Cd, 0.21-0.67 mg/L Pb and 0.11-0.12 mg/L Cr. In this study, it was shown that using contaminated water can increase the intake of heavy metals by vegetables. This is because the abundance of the heavy metals in the vegetables was related to the amounts in the water. The potential danger posed by heavy metals in agriculture is not only limited to the use of contaminated water and contamination of crops but also sludge. In a study done by Fliebbach et al. (1994) in Germany, it was found that sewage sludge contaminated by heavy metals (when added to agricultural soils) lowers both soil microbial biomass and microbial activity. The disturbances caused by heavy metals to microbial biomass and activity are known to be reflected in decreased litter decomposition and subsequently less-efficient soil nutrient cycling (Kandeler et al., 1996; Pennanen et al., 1996).

Remediation strategies

According to Alkorta et al. (2004), phytoremediation, an emerging cost-effective, non-intrusive, and aesthetically pleasing technology, that uses the remarkable ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues, appears very promising for the removal of pollutants from the environment. The plants that have been identified to be hyper accumulators of heavy metals are as follows (metal is put in brackets): *Thlaspi caerulescens* (Zn and Cd), *Berkheya coddii* (Ni), *Astragalus racemosa* (Se), *Iberis intermedia* (Tl), *Ipomoea alpine* (Cu), *Haumaniastrum robertii* (Co) and *Pteris vittata* (As). Although the natural propensity of plants to take up metals serve as a tool for phytoremediation, on the other hand it is a drawback to human health especially when contamination (by heavy metals) of food crops is too high (Evangelou et al., 2007).

Studies on remediation strategies in Malawi mostly used Moringa species. These studies include the one done by Robertsson (2014) who conducted a study on the possibility of *Moringa oleifera* seed powder to remove Cr from wastewater collected from Liwonde Tannery, Malawi. The study found that a combination of 5 g of river sand and 2 g of unpeeled *M. oleifera* seed powder was able to remove 72 and 97% of total and dissolved Cr, respectively in 100 mL of wastewater. This study showed that *M. oleifera* has a potential as a natural Cr removal agent that can be applied in many developing countries at a low cost. Another study was that done by Mataka et al. (2006) who showed that *M. stenoptala* and *M. oleifera* were able to remove Pb from water. In this study, it was shown that *M. stenoptala* was more effective than *M. oleifera*. In fact, with an initial dosage of 7ppm Pb in water, *M. stenoptala* seed powder (dosage 2.5 g/100 mL) was able to remove 96% Pb. The study further showed the great potential of low cost methods in remediation of heavy metals especially in developing countries like Malawi.

Studies done in other countries have indicated other potential methods which can be used in the removal of heavy metals. For example, a study by Yantasee et al. (2007) in USA found that superparamagnetic iron oxide (Fe_3O_4) nanoparticles with a surface functionalization of dimercaptosuccinic acid (DMSA) are an effective sorbent material for metals and some metalloids such as As, Hg, Ag, Pb, Cd, and Tl, which effectively bind to the DMSA ligands and the iron oxide lattices. In another study conducted in Italy by Marchiol et al. (2004) *Brassica napus* and *Raphanus sativus* showed some potential in the removal of heavy metals in marginally polluted soils. However, these species showed relatively low phytoremediation potential in soils contaminated with many heavy metals. In another study done by Bech et al. (1997) on a copper mine in northern Peru, unusually high concentrations of metals were detected in *Bidens cynapiifolia* of up to 1430, 437, 620 and 6510 $\mu g g^{-1}$for As, Zn, Cu and Al, respectively. Although this study was mainly on the assessment of heavy metal concentrations in the mine area, on the other hand it revealed the potential of *B*. *cynapiifolia* to accumulate heavy metals. In a study done by Meers et al. (2005) in Belgium, ethylene diamine tetraacetate (EDTA) and ethylene diamine disuccinate (EDDS) showed great potential to mobilise Cd, Cu, Pb, Ni and Zn from soils for easy uptake by plant shoots (*Helianthus annuus*). Another study done in Aznalcollar (Spain) by Clemente et al. (2005), found that *Brassica juncea* had the potential to accumulate Cu, Pb and Zn from soils especially at low pH levels. However, it is important to upscale these methods which are mostly laboratory based into full scale operations so as to remediate heavy metals in the environment.

CONCLUSION

Heavy metals especially Cd, Cr, Cu, Fe, Mn, Pb, Ni and Zn have been reported in Malawi in mainly water and soils. In most cases, the soils in urban areas especially those close to dumpsites have been found to be the most contaminated. Also surface water bodies seem to be contaminated by mostly industrial effluents. This is because studies in streams in Malawi, have shown that high concentrations of heavy metals are prevalent after they have passed though industrial areas. The results in Malawi compare well with studies done elsewhere in that urban streams and soils are mostly polluted by anthropogenic activities. In aquatic systems, studies have shown the potential of algae and earthworms to be used as biological indicators of metal pollution. On the other hand, sludge worms have high metabolic and excretion rates as such not good indicators of metal pollution.

Among the remediation strategies proposed, Moringa species have been favoured in the removal of heavy metals especially from water. These are also cheap since they are available locally. There is a need therefore for aggressiveness to environmental monitoring by relevant bodies both in Malawi and its region so that laboratory based methods should be upscaled (especially in developing countries) in remediation strategies for proper integrated water resources management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Characterization of pre-treated drill cutting waste and its use as fine aggregate in concrete

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Drill cuttings, generated in oil well drilling are managed to be disposed but will always have many environmental impacts. The innovation of this study was not only to produce a new and cost-effective material from drill cuttings, but also to mitigate its negative environmental impacts. Therefore, this article aims at characterizing and assessing behavior of drill cutting (DCI) deriving from well drilling activities in the State of Espírito Santo, Brazil, as a partial substitute to fine aggregate in concrete production. DCI was characterized using pH, X-ray Fluorescence Spectrometry (XRF), Fourier transform infrared (FTIR), X-ray diffraction (XRD), Thermo-gravimetric analysis (TG), Differential scanning calorimetry (DSC), and Scanning electron microscopy (SEM). The concretes produced had four percentages (0, 25, 50 and 100%) of their fine aggregate replaced with DCI. The study concretes were compared to one another regarding the variables compressive strength, Young's modulus and microstructure. The results show that the use of drill cutting in cement-based materials is linked to its previous characterization. All the samples have shown mechanic results above the projected values. The microstructural properties were not affected by the DCI replacement. DCI concretes can be used in the ready-made material production, where there is stricter control of the raw-materials employed.

Key words: Drill cuttings, characterization, concrete materials, waste utilization.

INTRODUCTION

Drill cuttings are tiny rock fragments impregnated with fluids used for lubricating and cooling down the drill during the oil well drilling process (Leonard and Stegemann, 2010). Managing this type of waste is one of the greatest concerns for the oil industry because of the significantly negative impact it causes to the environment due to the amount of inorganic and organic contaminants this material contains.

Exploration and development of drilling activities have expanded globally into such regions at the State of

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Espírito Santo, Brazil. In the State of Espírito Santo between 13 to 17 m^3, drill cuttings produced estimates of one hundred vertical meters drilled onshore according to Company Petrobras (Petrobras, 2010). Generally, the use of water-based muds generates 7,00013,000 bbl of waste per well. Depending on the depth and diameter of the well, about 1,400 to 2,800 bbl of that amount are drill cuttings (EPA, 1993). The presence and concentration of drill cutting contaminants depend on the fluid used, the geological formation drilled, the well phase and the water used in the fluid preparation. The main contaminants can be divided into hydrocarbons, water-soluble salts and, in some cases, heavy metals (Reis, 1996).

The drilling is divided into phases, usually two to three according to depth. In each of them, the diameter of the well is decreased generating a smaller volume of waste, per meter drilled, and with different contaminants. The techniques available for treating and disposing drill cuttings are chosen according to the cutting contamination, the local laws and the producing company's decision. Meanwhile, most of the drill cutting produced onshore in Brazil is disposed in dikes and landfills.

Some studies have been carried out in order to find a nobler destination to this material. In the civil construction industry, the studies on residue reuse point to stabilization/solidification of waste with Portland cement in concretes (Al-Ansary and Al-Tabbaa, 2007), including paving (Susich and Schwenne, 2004), landfill foundations (Dhir et al., 2010), unpaved road maintenance (Barnes, 2004), and ceramic materials (Pires, 2009; Chen et al., 2007).

According to these studies, the main problem that limits drill cutting reuse in concrete is the high concentration of organic components, and bentonite, which hinders the cement hydration process and decrease concrete compressive strength. It is important to highlight that most studies mentioned use waste that was taken from landfills or that was produced in labs, that is without strict control of the material and its contaminants. However, it is believed that waste derived from the first drilling stage can have different contaminant contents, which would offer better options of reuse.

Objectives and scope of this study

This study aimed at characterizing and assessing the potential use of drill cuttings obtained during the first drilling stage of oil wells, thermally pretreated at 100°C as partial replacement of sand in concrete production.

MATERIALS AND METHODS

The methodology adopted for characterizing the waste and analyzing the behavior of concretes produced using DCI instead of fine aggregate is described below. The study was divided into two stages. In the first stage the drill cuttings were characterized by the following tests: pH, DCI chemical, physical and microstructural characterization which was carried out using X-ray Fluorescence Spectrometry (XRF), infrared spectroscopy, grain grading analysis, SEM and X-ray diffraction, among other tests commonly used.

In the second stage, the study assessed the effect of substituting part of fine aggregates by different percentages of DCI (0, 25, 50, 100%) on mechanical properties and microstructure of concrete samples, based on compressive strength, Young's modulus, Scanning Electron Microscopy and X-ray diffraction.

Drill cuttings characterization

DCI was obtained during the first drilling stage of a well located onshore at Alegre's Farm (18° 59' 46'' S; 39° 52' 31'' W) in Jaguaré, the north of Espirito Santo State, Brazil. After being gathered, the sample was taken to the Laboratory of Building Materials (LEMAC) at the Federal University of Espírito Santo (UFES), Brazil, where it was dried in oven at 100°C and characterized in terms of chemical, physical and microstructural properties.

Chemical and physical properties

The chemical properties included determining pH (pH meter), chemical composition using XRF and infrared spectroscopy (IV). The physical properties which include grain size distribution by sieving, as well as laser diffraction using a Sympatech particle analyzer. Density measurement was taken using Archimedes' principle.

Microstructural analysis

For DCI microstructural analyses, the study employed X-ray diffraction tests (XRD) with a XRD 6000 Shimadzu diffractometer using Cu Kα radiation, voltage 40 kV, current 200 mA and 2θ scanning, ranging between 10 and 90°C. Thermal analysis by DSC using DSC 50 Shimadzu; TG-DTG analysis performed in the range of 25 to 1000°C (stripping gas: air and heating rate:20°C/min) and SEM observations on EVO 40 Carl Zeiss scanning electron microscope are used for examination of micromorphological characteristics of drill cuttings in natura. The mold prepared for SEM analysis was sputter-coated with a conductive layer of gold.

Analysis of concrete samples

In order to determine mechanical behavior of concretes produced with DCI, cylindrical test specimens measuring 10x20 cm were molded using the following materials: cement CP V ARI (ABNT, 1991), river sand (identified as fine aggregate G), pit sand (identified as fine aggregate F), granitic gravel, superplasticizer and drill cuttings (DCI). Concrete mix design complied with method EPUSP/IPT (Helene, Terzian, 1992) and its ratios are presented in Table 1. Test specimens were unmolded after 24 h, identified and placed in tanks containing a supersaturated lime solution.

Mechanical behavior analysis of concrete

Test specimens were submitted to compressive strength tests at 3,

Table 1. Mix proportions used for making concretes.

Compound	Cement	Fine aggregate G	Fine aggregate F	Coarse aggregate	DCI	Admixture	W/C[e]
R0 [a]	1	1.53	0.65	2.88	0.00	0.07	0.53
R20 [b]	1	1.53	0.52	2.88	0.13	0.27	0.53
R50 [c]	1	1.53	0.32	2.88	0.32	0.82	0.53
R100 [d]	1	1.53	0	2.88	0.65	0.82	0.53

[a]R0, 0% replacement of sand; [b] R20, 20% replacement of sand;[c] R50, 50% replacement of sand; [d]R100 ,100% replacement of sand; [e]W/C, water cement ratio.

Table 2. Characteristics of drill cutting and aggregates used in this study.

Component (%)	DCI	Fine aggregate G	Fine aggregate F
Bulk composition analysis (% dry mass)			
SiO_2	80.55	-	-
Al_2O_3	12.45	-	-
K_2O	4.3	-	-
CaO	1.28	-	-
Fe_2O_3	0.79	-	-
SO_3	0.37	-	-
MgO	-	-	-
TiO_2	0.20	-	-
SrO	0.02	-	-
Properties			
pH	8.47	-	-
Bulk density (g/cm³, wet mass)	1.19	1.48	1.63
Specific gravity	2.58	2.64	2.65
Loss-on-ignition (% dry mass)	0.04	-	-

7 and 28 days, in compliance with Brazilian standard NBR 5739 (ABNT, 2007) and Young's modulus test at 28 days, in compliance with Brazilian standard NBR 8522 (ABNT, 2003).

Microstructural analysis of concrete

Scanning electron microscopy (SEM): In order to verify if the replacement with DCI caused any significant change in the hydrated cement paste and in the transition zone compared to reference, concrete samples were investigated using the previously described SEM.

The samples were randomly collected from the core of the six test specimens that had been submitted to compressive strength test at 3, 7 and 28 days. The samples had their hydration interrupted at every age studied through the addition of acetone P.A. for five days. With their surfaces metalized by a layer of gold, the images were obtained using a secondary electron detector (SED) and microanalysis of a few samples in specific areas which was carried out using the Energy Dispersive X-ray Spectrometer (EDS).

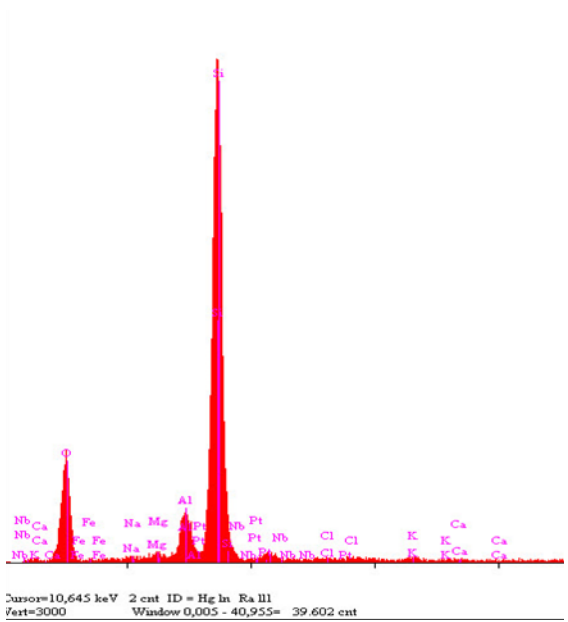
X-ray diffraction: The samples extracted from the test specimens undergoing compressive strength test at 28 days were collected randomly, ground for 10 sec in a disc mill and taken for mineral phase analysis through XRD. This analysis aimed at verifying whether any different mineral had been formed after interaction with DCI.

RESULTS AND DISCUSSION

Drill cuttings characterization

Chemical and physical characterization

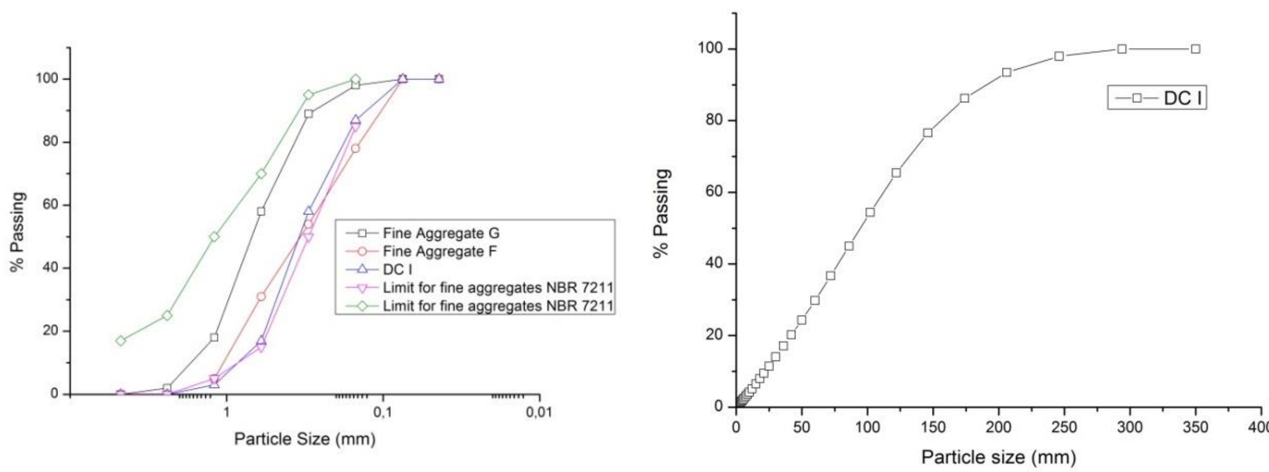
The chemical and physical characteristics of DCI are presented in Table 2. For comparison, the table also includes properties of the fine aggregates that would later be replaced with DCI in the composition of study concretes. The results obtained also show that DCI is alkaline, favoring its use in concretes, which need to keep their pH alkaline so as to avoid decalcification of the



Elt.	Line	Intensity (c/s)	Error 2-sig	Conc	Units	
O	Ka	60,63	2,284	40,696	wt.%	
Na	Ka	1,00	0,923	0,212	wt.%	
Mg	Ka	2,19	1,115	0,327	wt.%	
Al	Ka	36,92	2,040	4,773	wt.%	
Si	Ka	375,02	5,585	47,691	wt.%	
Cl	Ka	1,20	0,878	0,215	wt.%	
K	Ka	3,51	0,879	0,598	wt.%	
Ca	Ka	1,56	0,808	0,263	wt.%	
Fe	Ka	5,06	0,866	1,485	wt.%	
Nb	La	3,75	0,966	2,229	wt.%	
Pt	La	0,45	0,531	1,511	wt.%	
				100,000	wt.%	Total

kV	20,0
Takeoff Angle	35,0°
Elapsed Livetime	50,0

Figure 1. EDS of drill cuttings (DCI).



(a) **(b)**

Figure 2. (a) Grading of fine aggregate F, fine aggregate G, drill cuttings (DCI) and limits for fine aggregates according to the Brazilian standards. **(b)** Grading of drill cuttings (DCI) material passing through sieve size 0.075 mm based on laser scanning technique.

hydrated cement and consequent disaggregation (Priszkulnik, 2011).

Though EDS are presented in Figure 1, it is also possible to identify the intense presence of silicon, followed by elements oxygen, aluminum, iron, potassium, magnesium, calcium, chloride and sodium. DCI had its grain graded by sieving and the fractions passing through the 0.075 mm sieve were analyzed by laser diffraction. The results are shown in Figures 2a and b.

Based on grading analysis, we verified that DCI grain grading distribution which is most similar to that of sand F. Therefore, in the composition of concrete test specimens, only sand F was replaced with DCI, which would avoid a larger number of variables to be analyzed.

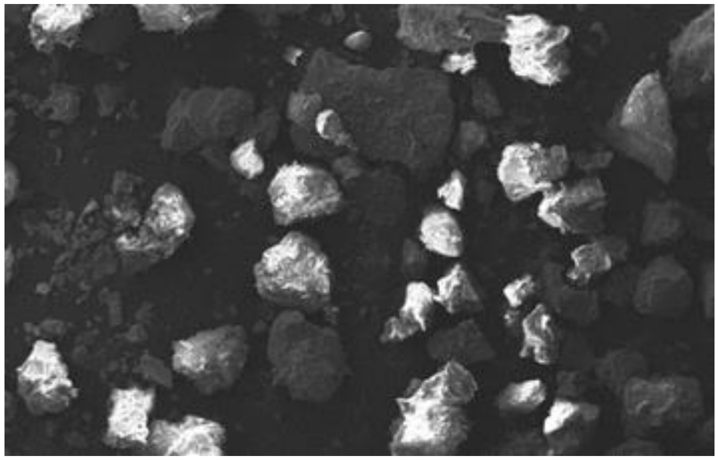


Figure 3. SEM photograph of DCI.

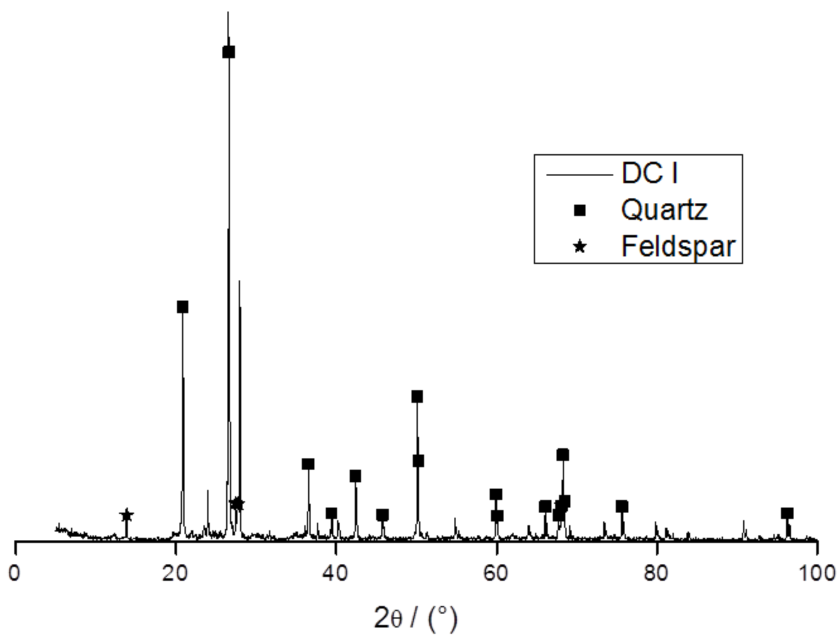


Figure 4. XRD sample of a DC I dried at 100 °C.

For DCI, the content of material passing through sieve 100 # was 13%. In the mass of this passing portion, it was observed that 4% of the whole sample contains silt. Clay fractions (< 2 µm) were not detected.

Microstructural analysis

Figures 3 and 4 show a SEM photograph and the results of x-ray diffraction of DCI, respectively.

The presence of different shapes and sizes of DCI particles can be noticed. This result can be justified by the type of drilling tool used, which consists of a steel tooth that scrapes the rock formation.

The presence of clay minerals was detected in DCI through XRD. However, we recommend further and more in-depth analyses that include the preparation of oriented, heated, and solvation with ethylene glycol (or glycerol) blades in order to effectively verify the presence of these minerals (Albers, 2002). The diffractogram in Figure 5

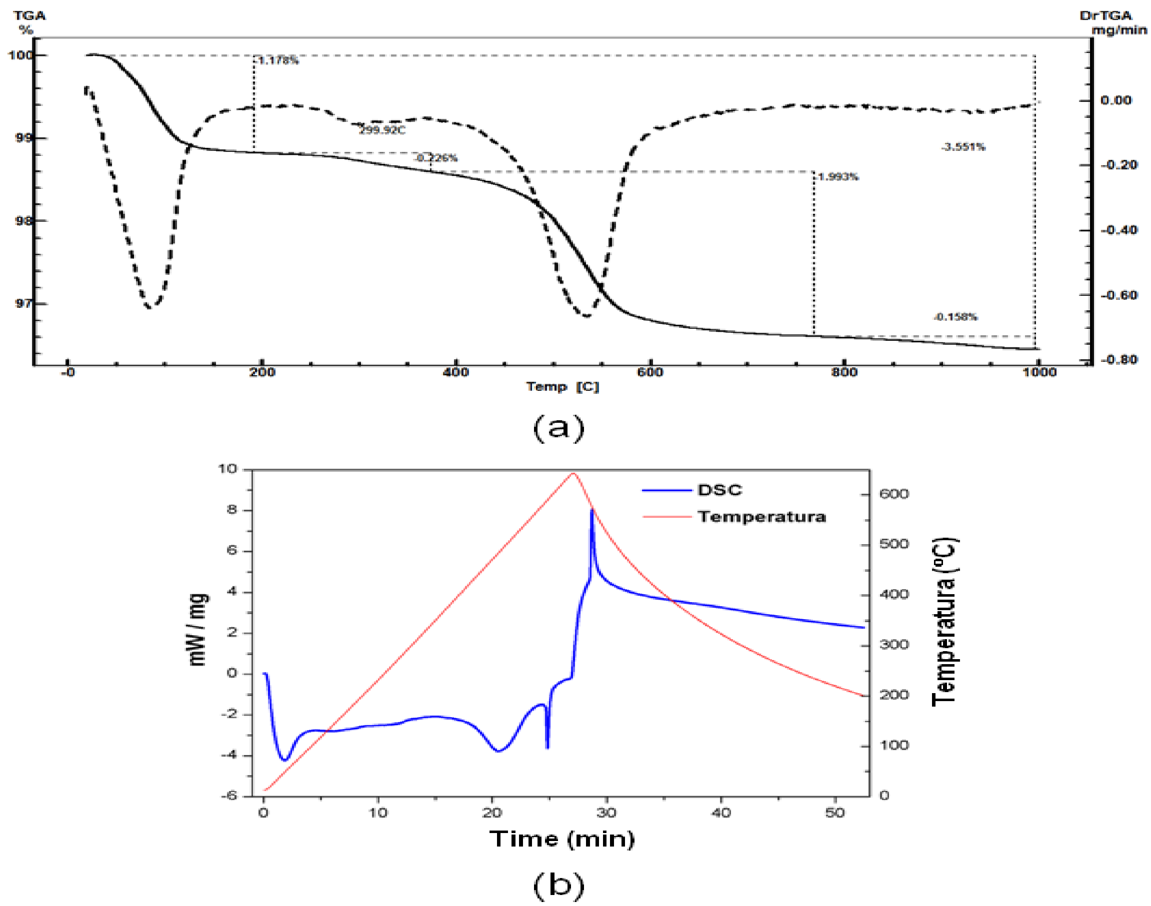


Figure 5. (a) TG-DTG of DCI, **(b)** DSC of DCI.

shows that the mineral predominantly found in DCI was quartz, followed by feldspar (albite and microcline). The rock drilled belongs to Rio Doce formation (from 0m to 792m) in the sedimentary basin of Espírito Santo. Figure 5 shows the TG curve of DCI.

The TG curve DCI (Figure 5a) shows mass loss of 4%, which can be explained by water loss. This result can also be ratified by the loss on ignition test described in Table 2. The material can then be considered as inorganic and does not contain organic contaminants. DSC (Figure 5b) shows loss of water in the first broad endothermic peak and second acute endothermic peak, which means that quartz changed from its alpha-crystallin state to beta at 573°C (Santos, 1992) confirm the major presence of this mineral. Spectrum of infrared spectroscopy analysis is shown in Figure 6.

The bands present at 3436, 3621 and 3698 cm^{-1} correspond to stretching of OH, which indicates the presence of water. This water can be trapped between the lamellas of clay minerals. At 467.5 and 534.7 cm^{-1}, the bands are associated to SiO deformations, whereas the bands at 912.9 and 1034 cm^{-1} are SiO stretching. All these vibrations are mainly characteristics of quartz.

Concrete analysis

Concrete mechanical properties

The average results of concrete compressive strength tests with substitutions of 0, 20, 50 and 100% at 3, 7 and 28 days are shown in Figure 7.

The results observed have a variation coefficient of 0.04% and the samples tested had density of 2330 kg/m^3 ± 4%.The compressive strength values at 28 days are between 46.25 and 43.34 MPa for the reference concrete (R 0) and substitution of 100% (R 100), respectively (Table 3). Results reveal that, the 100% substitution by DCI reduces compressive strength by 6.3% but the reduction in the consistency index increase the number

Table 3. Compressive strength and elastic modulus of concrete cured for 28 days.

Concrete	Compressive strength (MPa)	Standard deviation (%)	Elastic modulus (GPa)
R0	46.25	0.73	32.46
R20	45.19	1.46	31.87
R50	43.57	0.9	29.77
R100	43.34	1.4	29.99

R0, 0% replacement of sand; R20, 20% replacement of sand;R50, 50% replacement of sand; R100 ,100% replacement of sand.

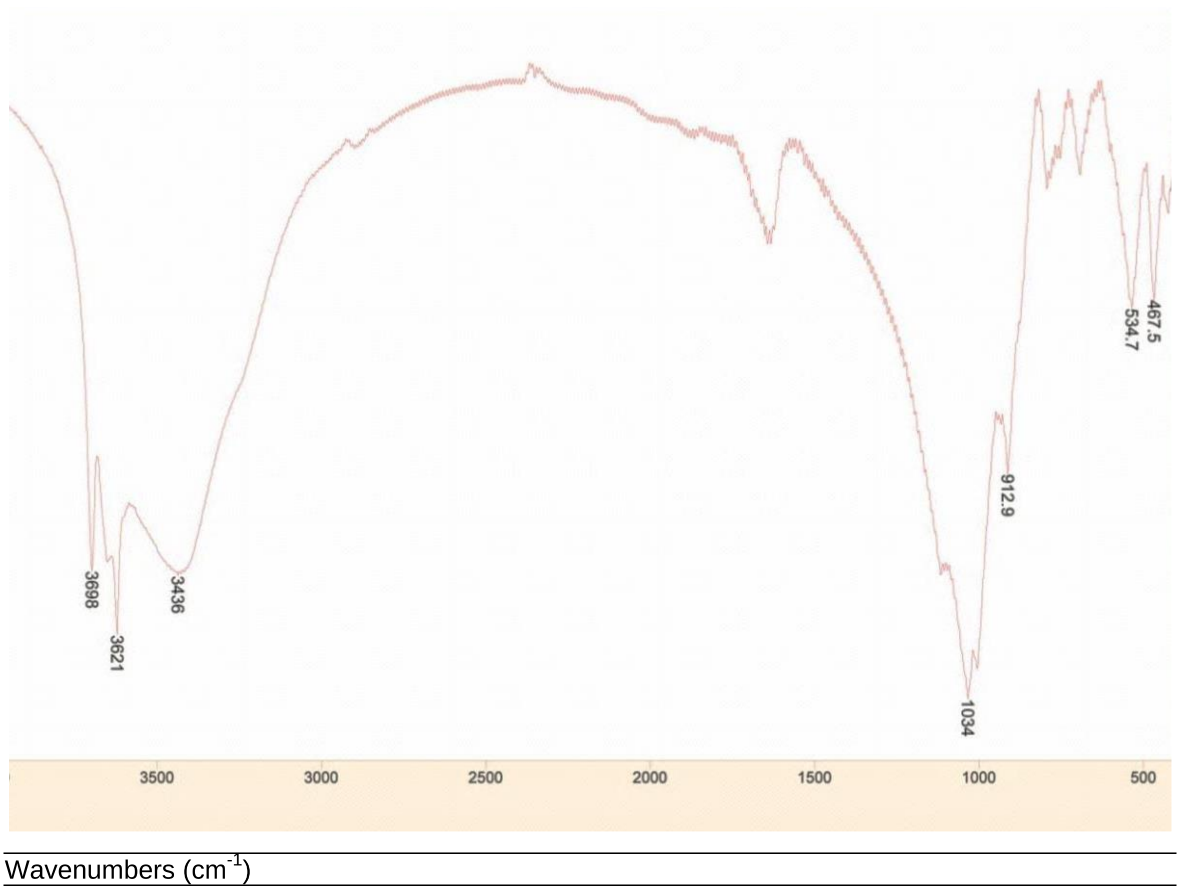


Figure 6. FTIR spectra of DC I.

of voids (Fialho, 2012).

Microstructural characterization confirms that, there was no delay in the reactions of hydration or formation of strange compounds. These findings suggest several options of reusing drill cuttings from the first drilling phase in cement-based building materials such as paving blocks, structural masonry blocks, curbs, stairs and other ready-made products that need lower compressive strength which are found.

Scanning electron microscopy (SEM)

Figure 8 shows the micrographic results of concrete samples obtained at 3, 7 and 28 days. It is noticeable that the micrographs show general characteristics associated to cement hydration products. The absence of ettringite, acicular tri-sulfur aluminate crystals of hydrated calcium looking like needles and sulfur aluminate of hydrated calcium was verified even in the first ages.

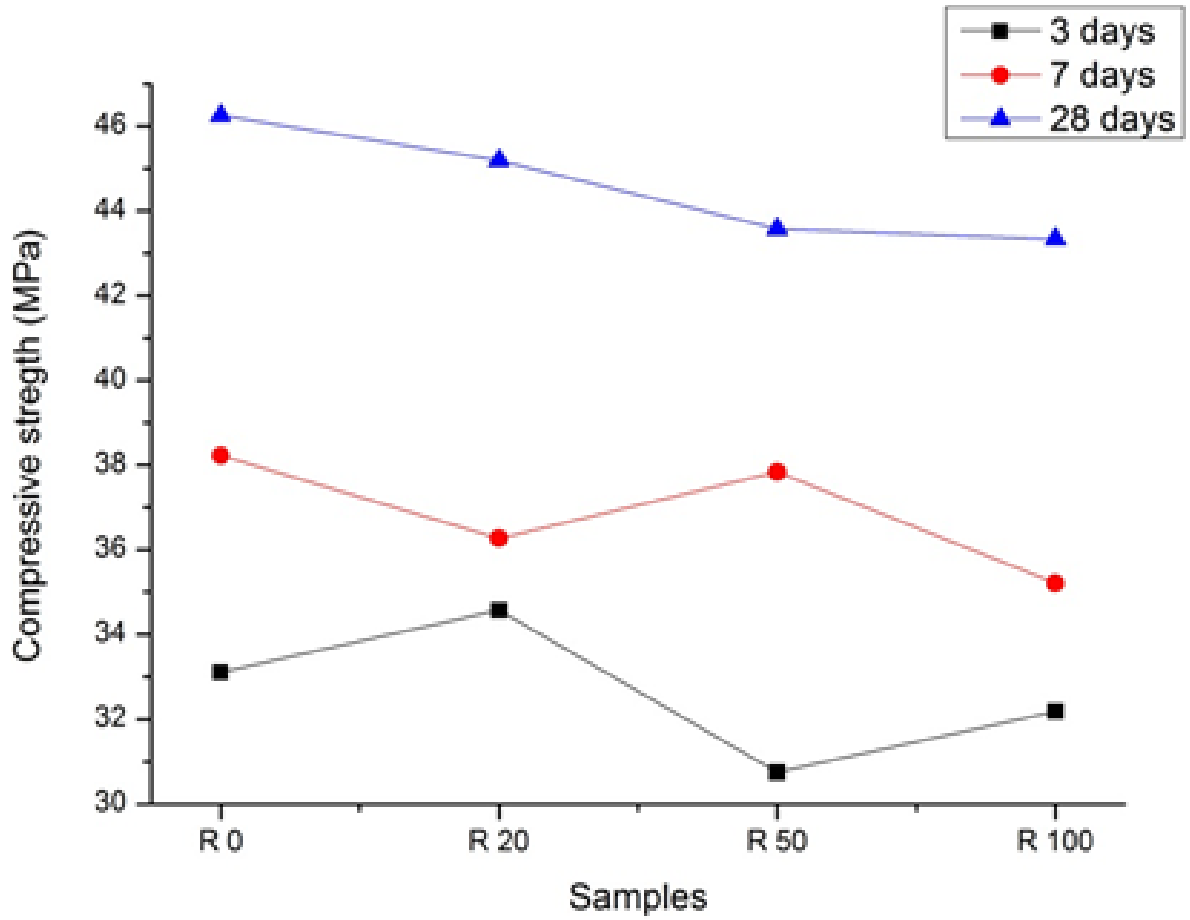


Figure 7. Unconfined compressive strength.

Micrographs at 3, 7 and 28 days show the evolution of fibrous crystals of hydrated calcium silicate looking like leaves and brad hexagonal prismatic crystals, that can be typical of portlandite (calcium hydroxide) and aluminate of hydrated calcium.

We can also see that the concretes presented are characterized by a compact structure. The structure of the pores in the three percentages evaluated does not show marked morphological changes compared to control. This can suggest that the presence of DCI did not influence the formation of hydrating products negatively. Clay minerals could not be seen either, because of their micro or nanometric dimensions. The microcrystals of most clay minerals can only be seen through transmission electron microscopy (TEM); only few can be observed through SEM (Coelho, 2012). Although compressive strength statistical analysis shows reduction among the groups, the microstructural analyses do not show visible differences between the samples analyzed. EDS chemical analysis shows that concretes with DCI did not change their calcium and silicon contents, which means that there was no occurrence of pozzolanic reactions. This effect was already expected because of the absence of free silica and the waste grain grading (Taylor, 1964). The compressive strength results confirmed these findings.

X-ray diffraction (XRD)

Figure 9 shows the XRD results for concrete R 100. XRD results show that the characteristic peaks of reference concrete are quartz (silicon oxide), portlandite (calcium hydroxide), feldspar (microcline and albite) and alite (tricalcium silicate - C_3S). The reference mixes R 20, R50 and R 100 contained quartz (silicon oxide), portlandite (calcium hydroxide), and feldspar (microcline and albite). No mineral considered deleterious to concrete was found. The conclusion is that replacing sand with DCI did not affect the mineralogical compositions in the study

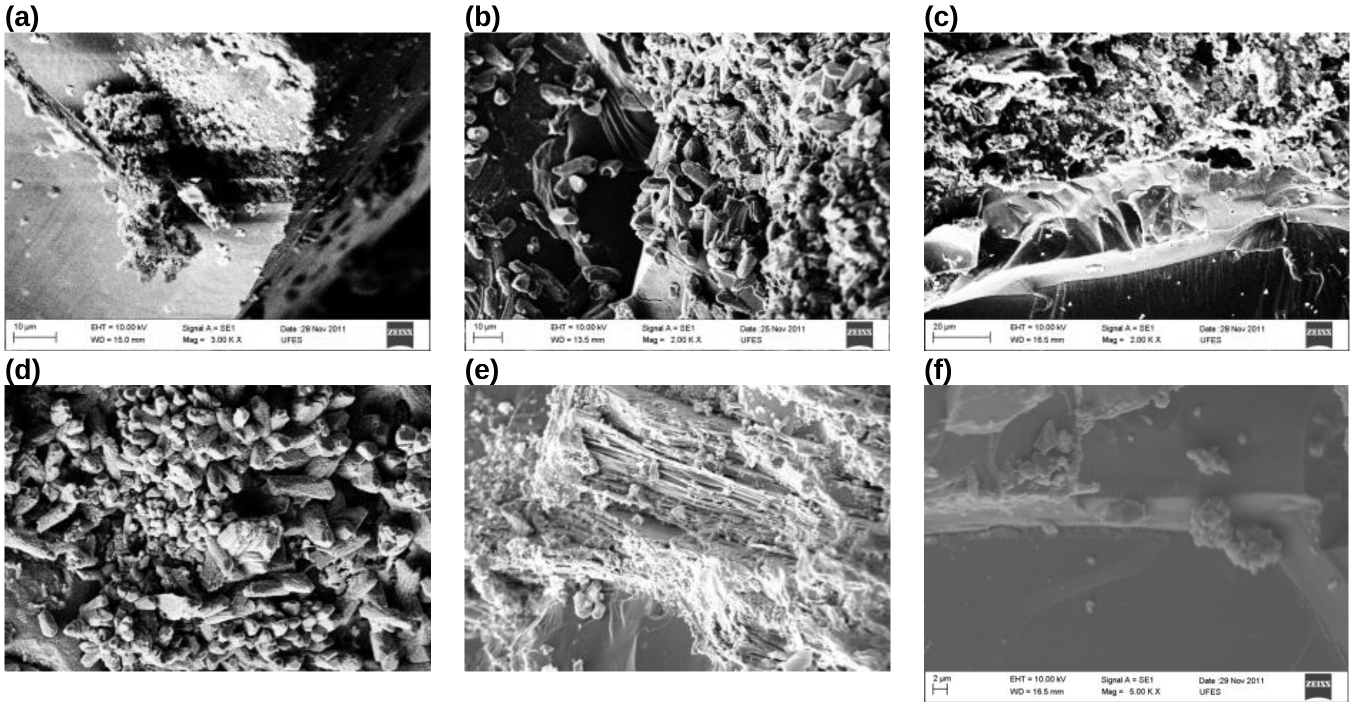


Figure 8. (a) R 0, 3 days b) R 0, 7 days c) R 0, 28 days, d) R 20, 3 days, (e)R 20,7 days (f) R 20,28 days – Magnification 2000x.

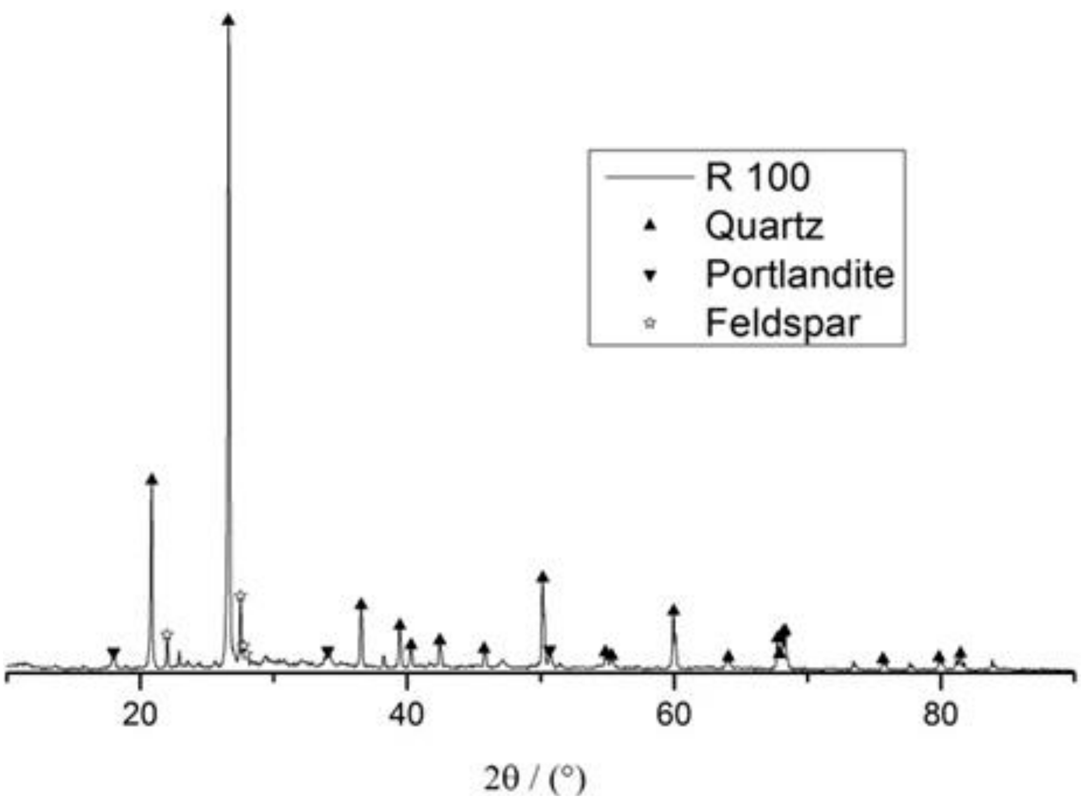


Figure 9. Qualitative phase determination of concrete with drill cuttings – R 100.

concretes.

Conclusions

Based on the test results, the following conclusions can be drawn regarding DCI characterization:

(1) DCI values are considered normal for fine aggregate like grain size distribution, fineness modulus, maximum characteristic size, specific gravity, and unit gravity.

(2) DCI has an alkaline nature. X-ray Fluorescence analysis which are found as the main elements are expressed in its most stable oxides: silicone and aluminum.

(3) Energy dispersive X-ray identified elements sodium and chlorine, which may be an indication of the presence of small concentrations of sodium chloride.

(4) TG and DSC analyses indicate that, DCI is an inorganic but has free organic contaminations. The presence of quartz was also confirmed.

(5) X-ray diffraction and petrographic analyses identified quartz and feldspar as its main minerals. X-ray diffraction shows essentially crystalline nature. The rock drilled was sandstone in the Rio Doce formation.

Concerning the study concretes:

(1) The ratios tested reduce compressive strength significantly. However, they do not compromise Young's modulus.

(2) The microstructural properties of concrete were not affected. The micrographs presented show general characteristics associated to cement hydration products. Mineral which phases differently from expectations were found.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Participatory approach to conservation and management of protected areas in Nigeria: Case study of Osse River Park Project

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Stakeholder involvement and participation are essential in achieving sustainable integration and sound environmental management of protected areas in Nigeria. Involvement and participation of local communities in conservation and management of Osse River Park were assessed through administration of structured questionnaires while relevant State Government Ministries in Environmental and Nature Resources Management and Non-Governmental Organizations (NGOs) were interviewed to complement the study. Although the local communities were observed to be involved at the inception of the Park, their participation in park management is presently low (25%). Accordingly, 70% of the respondent claimed that the government and NGOs invested more in environmental education, park protection and surveillance than in meeting socio-economic needs of the people. Small proportion of the respondents identified distribution of plant seedlings (20%) and intensification of conservation education (10%) as an urgent need. This result suggests the need to increase financing from the present 5 to 25% NGO's input in fund raising and the government's commitment in finance. The study identified improving stakeholders' relations, capacity building, and integrating community-based natural resource management as important. It was recommended that the ministries and NGOs engaged in environmental and biodiversity conservation which direct more efforts toward the development of sustainable practices that facilitate stakeholders' participation in the integration process.

Key words: Capacity building, conservation education, stakeholder's involvement and participation, sustainable development.

INTRODUCTION

A protected area is an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources and managed through legal or other effective means

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(International Union for Conservation of Nature/World Conservation Monitoring Centre (IUCN/WCMC), 1994). According to Dudley (2008), all protected areas should aim to conserve the composition, structure, function and evolutionary potential of biodiversity. Based on management objectives, the International Union for Conservation of Nature and Natural Resources (IUCN) recognizes six categories of protected areas (Phillips, 2002).

National Parks are classified as protected areas managed for ecosystem conservation and recreation. They fall under Category II of protected areas with clear boundaries drawn sufficiently to contain one or more entire ecosystem which are not subject to material modification by human exploitation or occupation (IUCN/WCMC, 1994). National Parks are therefore considered as gene pool of immeasurable biodiversity.

Biological diversity (or biodiversity) includes all the different plants, animals and microorganisms, the genes they contain and the ecosystems of which they form a part (National Environmental Awareness Campaign (NEAC), 2012). The Royal Society (2003) asserts that our dependence on biodiversity is absolute and 'without it, humans would not be able to survive'. Ecosystem services were derived from biodiversity including domesticated or wild species for food, fibres, fuel, pharmaceuticals and many other purposes. In addition, added value was derived from the influence of biodiversity on climate regulation, water purification, soil formation, flood prevention and nutrient cycling, etc. The impact of biodiversity on our culture and its aesthetic value are also immense (Daily, 1997; Balmford et al., 2002). Biodiversity is thus fundamental for meeting current and future social, cultural, ecological and economic livelihoods demands of the communities and it is an essential component of sustainable development. Thus, any attempt to restrict human from unsustainable exploitation of natural resources tend to receive precarious resistance. Rather than enforcing law, arrest and prosecuting the locals that are custodian of these resources, there is need to develop techniques that will ensure that their needs are integrated.

In many cases, traditional approaches to park management through law enforcement have been unable to balance the competitive objectives of conserving biodiversity (Wells and Brandon, 1992). Hence, integrated approaches have evolved to facilitate interaction and participation of the relevant stakeholders in park management. Integrated Natural Resource Management (INMR) is a holistic and multidisplinary approach that provides opportunity for interaction and involvement of relevant stakeholders. IUCN recognizes INMR approach as a way to establish and manage protected area and make substantive contributions to conservation strategy, if only the skill in selecting, combining and processing INMP approach is developed (Dudley, 2008). World Bank (1990), launched Integrated Conservation and Development Projects (ICDPs) as a key initiative aimed at meeting the increasing demands on biodiversity resources (Wells et al., 1992). With ICDPs in place, the numerous challenges facing biodiversity resources are hoped to be receiving necessary attentions.

Proper selection, combination and processing of Integrated Natural Resource Management approach with other similar community based practices like Community Based Ecotourism Practice will provide opportunity for achieving sustainable development whereby social, cultural and economic needs of the communities' vis-à-vis biodiversity conservation objectives are met (Oladeji, 2015). As part of the aim of the guidelines prepared by the general assembly of International Council for Monuments and Sites (ICOMOS) at its tenth session in 1993; it was noted that sustainable management strategies for change which respect cultural heritage require the integration of conservation attitudes with contemporary economic and social goals including tourism (ICOMOS, 1993). According to UNDP (2004), Community Management of Protected Areas Conservation (COMPACT) is a demonstration project within the context of Integrated Conservation and Development Projects (ICDPs) born out of the need to redress the imbalance between natural resources conservation and the local community's needs. In view of the peculiarity of this project targeted at promoting visit to the park as a means of generating revenue, ensure conservation of the rich biodiversity resources of the park, and improving the social and economic lives of the host communities, ecotourism should be given attention. Ecotourism is considered as an environmentally responsible and sustainable form of visit to nature based site in order to appreciate nature in its pristine and other accompanied cultural features. Ecotourism tends to minimize negative impact on the ecosystem while optimizing contribution to conservation and improvement of socioeconomic benefit to the local communities. Ecotourism has been embraced over the years as an ideal mechanism for attaining both the economic and ecological sustainability. It has brought the promise of achieving conservation goals, improving the well-being of local communities and generating new business promising a rare win-win-win situation (Drumm and Moore, 2002). Ecotourism improves understanding, facilitate participation, and involvement among the stakeholders. Ecotourism industry creates synergy between conservation and social-economic needs of the local communities.

Research interest in understating stakeholders' participation and involvement in the management of protected areas has been increasing in recent times. This is a serious consideration for this work hinged on the need to devise strategies for effective management and conservation of rich biodiversity resources in Osse River Park, with attendants increasing anthropogenic activities such as clear felling, encroachment, unsustainable harvest and other social-ecological crisis emanating across protected areas as reported in literatures (Swarthout and Steidl, 2001; Oladeji et al., 2012; Johnson et al., 2005). Another reason for increasing interest in stakeholder's participation and involvement is that managers of natural resources are facing challenges in designing a conceptual framework targeted at sustainable management of biodiversity resources in such a way that negative ecological impact is minimized and improve livelihood and economic well-being of the local in the developing countries especially those that are leaving adjacent to protected areas are guaranteed.

Stakeholders may include a variety of people, from members of government and industry to indigenous and international non-governmental organizations (NGOs), and may engage in diverse activities to make a living, thereby using resources in a multiplicity of ways. NGOs as part of stakeholders in conservation and management of protected areas played significant roles in sensitizing the community, in conflict resolution and in provision of funds and in training as reported in Georgian-Abkhazian, Southern Russia and South Western Nigeria (Stewart, 2004; Oladeji and Afolayan, 2009). Stewart (2004) emphasized that the advantages of NGOs in conflict prevention are that they 'do not carry the baggage of government statuses, are closer to and better informed about developments within the community, are 'often made up of people of stature within communities' and promote functional concerns and therefore can transcend ethnic boundaries.

Local communities are another relevant stakeholder that is largely recognized by conservationists and development practitioners in view of the crucial roles being play in the management of natural resources and habitats and many have adopted 'if it pays it stays' principle (Rosario, 1997). The United Nation Conference on Environment and Development (UNED) (1992) stressed that policy development and implementation on biodiversity should take place in cooperation with all interested parties, especially the private sector and local and indigenous communities. The emphasis is on recognizing local communities adjoining protected areas as the key stakeholder in decision making and management as a way to ensure their cooperation and involvement in biodiversity conservation. According to Skidmore et al. (2006), the local community should not be forced, but rather be given opportunity to participate and involve in projects which affect their lives. Such an approach upheld the basic rights and a fundamental principle of democracy. Organizing the people into groups facilitate group discussions, dialogue and equal participation of the stakeholders. MacDonald and Service (2007) hold that the task of designing modern, crosscutting, transparent, evidence-based interdisciplinary decision making is not only conceptually challenging, but also necessitates a huge increase in local capacity for democracy and decision making.

The main actor in traditional management of natural resources is the Government. Government exists at the Local, State, National and Global levels; their level of involvement in conservation and management of park resources can therefore not be ignored. In contrast to the "traditional paradigm", in which protected areas were managed by the central government, a "new paradigm" emphasis cooperation in the governance of protected area. For instance, Federal Government of Nigeria through National Park Service, Federal Ministry of Environment and Natural Resources oversee management of National Parks with minimal or without external input. Another challenge of traditional management of protected area is that it is being dominated by natural scientists, thereby failed to address the social, economic and political needs of the community. The new paradigm as being proposed in this study will ensure sustainable management through cooperation, participation and involvement of relevant stakeholders; it will serve as blueprint for sustainable park management in Nigeria and other countries where traditional approach to park management is yet to be abolished. Phillips (2003) reported that traditional management of protected areas dominated by natural scientists is gradually being replaced by socio political processes requiring consultations, sensitivity, and astute judgment.

Osse River Park formerly known as Ifon Game reserve is presently undergoing reformation and transformation aimed at enlisting it as one of the National Parks in Nigeria. One major challenge that protected areas in Nigeria is having is in the area of transformation from game reserve to National Park. Ifon Game reserve was under the management of Ondo State Government under direct statutory supervision and management of the Department of Wildlife, Ministry of Natural Resource, Ondo-State, while the Ministry of Environment, Department of Natural resources plays the backup role. Presently, NGO such as Nigerian Conservation Foundation (NCF) with other registered NGO in the state such as Nigerian Environmental Conservation Organization (NECOR) and Nigerian Environmental Study Team (NEST) are considered to be playing complementary roles in the efforts to transform the game reserve and ensuring its enlistment as one of the national parks in Nigeria. Unique fauna and flora resources in the game reserve as well as the rich diverse cultural values of the host communities have been assessed and documented (Agbelusi and Afolayan, 1991; NCF, 2007). The present management technique is being considered as a traditional approach to natural resource management and it is not sustainable to achieve the set objectives. There is therefore a need for a change of paradigms from top-down to a holistic and participatory approach. Integrated natural resource management approach will go a long

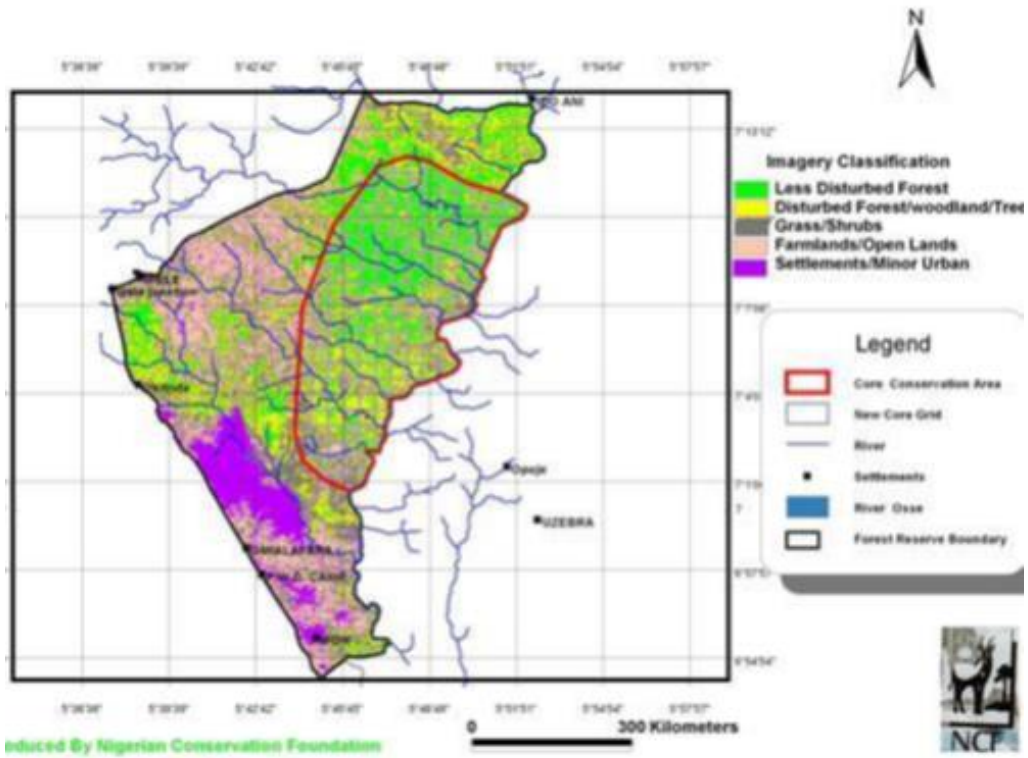

Figure 1. Map of Osse River Park.

way in addressing the identified imbalance among the stakeholders. This strategy will facilitate sustainable conservation and management of the park through proper participation and involvement of all the stake-holders. It is recommended that government established ministries/organizations and environmental NGO's increased focus on research in biodiversity conservation and development of community based practices in the integration process. Simpson (2001) holds that the sustainable approach to planning is based on the achievement of two prerequisites: a strategic and long-term orientation in planning and multiple stakeholder participation in the planning process. The local communities, the government and NGOs should consider their roles and ensue that these are properly integrated in the planning process in order to achieve the aim of conserving the biodiversity in the park.

METHODOLOGY

Study area

Osse River Park is located in Osse Local Government area of Ondo State, Nigeria. The park covers a total area of 282.72 km^2 which is equivalent to 8.4% of Ondo State. It is situated between 6°40′ N and 7° 5 ′N and 5°4 ′3″E and 5° 55 ′ E. It is bounded in the west and south by the Akure Benin express road, on the north west by Ipele-Ido-ani express way and on the east by river Osse and Asaboro rubber plantation (NCF, 2007). Osse River Park has a unique ecosystem diversity because of its high forest vegetation as well as Savanna. The three major vegetation types in the park include tropical rainforest area covering 50% (150.22 km^2), savanna woodland including forest/savanna mosaic which covers an area of 132.48 km^2 and the riverine forest which occurs along the courses of the major rivers draining the reserve (Figure 1). In view of its location, it is easily accessible from all sides by visitors coming from the Southern and Northern part of Nigeria. It is about 20 km from Owo, 80 km from Akure, 6 km from Ifon and about 80 km from Benin City. The reserve is drained by five important rivers which include Big Osse, little Osse and river Uwese, Okua and Orokin. Osse River Park is surrounded by various communities including towns, villages, settlement and camps among which are: Ifon, Igbo-nla, Ikaro, Uwesse camp, Omi-arafa, Ori-ohi camp, Ipele, Igbogburu (Ido-ani), Ago-Igbira, Ago-Alao, Ofale and Elegbeka. While Ipele is under Owo Local Government Area, other communities fall under Osse Local Government Area. None of these communities is situated within the park protected area. According to Federal Republic of Nigeria Official Gazette (FRNOG, 2009), the population of Ose Local Government Area was put at 144,139 with male constituting the highest percentage of 50.73%. However, this official gazette lacks breakdown of the figure for each of the selected communities unlike the National Population Commission Census Final results for 1991.

Methods of data collection

Qualitative and quantitative methods of social survey were adopted

Table 1. Location of the respondents.

Location	Frequency	Percentage
Elegbeka	88	22.6
Ifon	116	29.7
Idoani	84	21.5
Ipele	102	26.2
Total	390	100

in this research work. The administered questionnaire to the host communities was designed and structured to include questions on the demographic characteristics of the respondents; level of awareness on biodiversity conservation education; method of awareness; involvement in identified biodiversity conservation activities; areas of involvement in park management and suggestion for improve participation and involvement. Although two major sources of information on biodiversity conservation education were identified to include media and community sensitization programs, however level of awareness on biodiversity education was measured as either high or low based on (1) the frequency of hearing the jingles through media or number of attendance at the community sensitization programs and (2) number of sources of information. Respondents that signified that they have listened to jingles on radio or television not less than ten times within a year were rated high. Also rated high, are those that signified that they have attended organized community sensitization programs for at least three times within a year. All the respondents that indicated otherwise were rated low. Respondents were asked to indicate any or both of the biodiversity conservation related activities identified to be practicing. They were also given option to indicate if neither. The two identified biodiversity conservation related activities were planting of trees to serve as fence, shade, edible fruit and other economic advantages; and domestication of grasscutter and snail. Areas of involvement in park management activities are divided into involvement in park surveillance/protection and serving as member of community advocacy group. Community advocacy group consist of people that facilitate discussion between the government and the community, for instance, whenever community sensitization programmes are to be organized, they are those that plan on modalities to execute this act. Park surveillance members are members of the community employed as uniform men by the government to assist in monitoring the park.

The structured questionnaire was self-administered among the four neighbouring communities. The names of these communities were Elegbeka, Ifon and Ido-ani in Ose Local Government Area and Ipele in Owo Local Government Area. Local Government Areas were selected through a multi-stage approach. In the first stage adjoining communities were purposively selected based on their proximity to the park (Sarantakos, 1988; Bamgboye and Okoruwa, 2009) with consideration of the potential for the locals to engage in anthropogenic activities that have direct impacts on the forest resources (Oladeji et al., 2012) (Table 1). In the second stage, the communities were stratified into streets and quarters while in the third and the last stage, the respondents were randomly selected. A total of three hundred and ninety (390) respondents at house levels were randomly selected across the named streets and quarters in each community (Dohrmann et al., 2006; Kennel and Liu, 2011). Fifteen key informants considered to be knowledgeable about the social and economic livelihood of the people haven stayed in these communities for over 20 years were selected for interaction in each community making a total of 60 key informants in all. Interview guide was prepared to facilitate conversation with the government and NGO. It contains guided questions such as level and areas of involvement in biodiversity conservation and park management and percentage of financial contribution.

Interview

In order to complement this research findings, oral interview were held with the staff (n=20) of the two relevant Government Ministries and with a staff of Nigerian Conservation Foundation (NCF). Ten respondents were purposely selected in each department in the two relevant ministries. The staff from these two departments were purposively selected based on the fact that they represent government on issues pertaining to conservation and management of the park. The two government ministries are the Ministry of Agriculture and Ministry of Environment and Departments of Wildlife and Department of Natural Resources, respectively. These ministries via the affiliated departments are saddle with the responsibilities to oversee Biodiversity Conservation and Environmental Management in Ondo-State. A formal interview was conducted for the project monitoring officer of NCF assigned to Osse River Park Project. He was purposely assigned by NCF as the representative of the organization as at the time of conducting this research work. He was the only staff from NCF that the researchers were directed to meet in order to collect relevant information on the efforts and contributions of NCF to Osse River Project. Other NGO like Nigerian Environmental Conservation Organisation (NECOR) was reported to register with Ondo State Ministry of Environment and participate actively in conservation education in adjoining communities. The researchers were directed to meet members of this organization to collaborate their findings.

Data analysis

The collected data were analyzed both qualitatively and quantitatively. Data collected through the administered questionnaire was analyzed quantitatively using Statistical Packages for Social scientist (SPSS) version 20 and presented in tables. Information obtained on the interview held with the key informants and NGOs was analyzed qualitatively.

RESULTS

Demographic information of the respondents

Of the total number of persons interviewed, 56.3% were male and 43.7% were female, >20 years were 10.2%, 31.5% were between 30 and 40 years, >50 were 11.4%

Table 2. Social and demographic characteristics of the respondents.

Age	Frequency	Percentage
>20	40	10.2
21-30	115	29.5
31-40	123	31.5
41-50	68	17.4
>50	44	11.4
Educational background		
Primary	112	28.7
Secondary	186	47.7
Tertiary	68	17.4
No formal education	24	6.2
Occupation		
Farming	215	55
Trading (in non-forest/agricultural items and agricultural produce)	101	26
Artisan	51	13
Civil servant	23	6
Period of stay		
1-10	110	28
11-20	101	26
21-30	55	14
31-40	56	15
41-50	48	12
>50	20	5
Total	390	100

(Table 2). A small number (6.2%) had no formal education. Subsistence farming was the most common form of occupation (55%), followed by sales of non-agricultural and agricultural produce (26%) and artisans (13%). Analysis of result obtained on the period of stay in the community revealed that large percentage of the respondents has spent over 30 years in these communities.

Knowledge and participation in biodiversity conservation

Greater percentage of the respondents (62%) indicated that their level of awareness on biodiversity conservation was high (Table 3). This can also be affirmed through the various means by which these (62%) respondents indicated that they got the awareness. For instance large percentage of the respondents (77%) claimed that they were aware of biodiversity conservation education through repeated jingles of not less than ten times within a year on media (radio and television) on the danger of bush burning, indiscriminate killing of wild animals and the need to promote domestication of plants and animals. Respondents that expressed their level of awareness based on the fact that they have attended sensitization meetings or programmes (such as World Environment Day, Tree Planting Day and International Day of Biodiversity) organized in the community on the need to desist from activities such as bush burning especially during the dry season period to avoid inferno and uncontrolled killing of wild animals were considerably low (16%) (Table 4). However, despite the high level of awareness on biodiversity conservation education in the study area, relatively low percentage (36%) of the respondents are engaging in tree planting and wild animal domestication for social and economic purposes. Others (64%) indicated that they did not engage in any of these acts considered as biodiversity conservation activities. Tree planting exercise was rated the highest as a regular practice (23%) followed by domestication of wild animals such as rearing of grasscutter/giant rat and snail (13%) (Table 5). Species of trees that are being planted because of their social and economic importance includes

Table 3. Awareness on conservation.

Awareness on conservation	Frequency	Percentage
High	242	62
Low	148	38
Total	390	100

Table 4. Medium of awareness.

Medium of awareness	Frequency	Percentage
Media	301	77
Community/Sensitization	62	16
No respond	27	7
Total	390	100

Table 5. Biodiversity conservation activities.

Efforts	Frequency	Percentage
Tree planting *Tectona grandis*, *Nauclea diderrichi, Khaya spp.,* and *Gmelina arborea*	90	23
Wild animal domestication e.g grasscutter domestication and snailry	50	13
Not engaging in conservation acts	250	64
Total	390	100

Table 6. Involvement in park management activities.

Involvement	Frequency	Percentage
Involve	35	9
Not involve	250	64
No response	105	27
Total	390	100

Table 7. Areas of involvement in park management activities.

Areas of involvement	Frequency	Percentage
Park surveillance/protection	19	54
Community advocacy/informant	16	46
Total	35	100

Teak *Tectona grandis*, *Nauclea diderrichi, Khaya* species, and *Gmelina arborea* (Table 5). Relatively low percentage of the respondents (9%) indicated that they involve in park management activities (park surveillance/protection and community advocacy group); those that did not involve represent the highest percentage (64%) while others (27%) did not respond (Table 6). The areas of involvement as indicated by the respondents include park surveillance/protection (54%) and community advocacy group (46%) (Table 7). Result of the interview held with the local key informants was used to complement information obtained through administration of questionnaire on the traditional occupation of the respondents to include trading in sales of bush meat, hunting, fishing,

Table 8. Suggestions for improve biodiversity conservation and communities participation.

Suggestion	Frequency	Percentage
Creating employment	125	32
Capacity building training	117	30
Provision of inputs	78	20
Intensive conservation education	39	10
Change in management approach	31	8
Total	390	100

Table 9. Level of involvement, areas of involvement and percentage of financial contributions to biodiversity conservation.

Level of involvement in biodiversity conservation	Ministry of Agriculture Department of Wildlife		Ministry of Environment Department of Natural Resources	
	Frequency	Percentage	Frequency	Percentage
Fully involved	9	90	-	-
Moderately involved	-	-	2	20
Partially involved	1	10	8	80
Areas of involvement in biodiversity conservation				
Environmental Education and awareness	5	50	5	50
Finance	1	10	1	10
Advocacy	1	10	1	10
Provision of input/research	2	20	2	20
Protection and Surveillance	1	10	0	0
No response	0	0	1	10
Percentage of financial commitment				
10%	-	0	-	0
25%	2	20	1	10
50%	-	0	-	0
No response	8	80	9	90
Total	10	100	10	100

honey tapping, produce marketing and gathering of forest fruit or seed for sales. Fruits/seeds from species of trees such as *Arvingia gabonensis, Bligha sapida* and *Parkia biglobosa* are collected in the forest for sales as a mean of livelihood. The informants indicated that the categories of people involve in these activities were not constituted into group. Thus meeting them to discuss on their mode of activities in the course of carrying out this study was difficult. Suggestions for improve biodiversity conservation and increase communities' participation in the management of the park were rated in order of priority to include creating employment/job opportunities for the people (32%), provision of capacity building training/financial empowerment for the locals to start their small scale businesses (30%), and change in the management approach to conservation (8%) (Table 8). Only 20 and 10% of the respondents identified provision of inputs such as tree seedlings, boot, and uniform for those in park surveillance and intensification of conservation education through media and community sensitization as needing attention, respectively.

Result of the analysis of interview held with the government agencies

Result of the analysis of interview held with the staff of the Ministry of Agriculture and Staff of the Ministry of Environment is revealing (Table 9). The result shows that the Ministry of Agriculture is involved in creation of environmental education (50%), protection and surveillance (10%), distribution of inputs such as tree seedlings (20%), advocacy (10%) and finance (10%). Based on the responses received from the staff, the level of financial commitment of the ministry is put at 25% level. The level of involvement of the people in the four adjoining local communities on biodiversity conservation activities and park management at the inception was considered to be high (75%) unlike at present which is very low (25%). This explains the reason for attendant increasing rate of anthropogenic activities threatening biodiversity resources being conserved in the park while relatively few of the people engage in community advocacy meetings (46%) (Table 7). The list of anthropogenic activities as being kept by the ministry include illegal lumbering activities, forest fragmentation/land clearing for farming and cultivation of *marijuana* hemp, hunting and poaching.

In the Ministry of Environment, their areas of involvement in biodiversity conservation included environmental education (50%), provision of input such as seedlings (20%), finance (10%), and advocacy (10%), while 10% did not respond. The level of financial contribution of the ministry among the 10% that indicated financing as an area of involvement of the ministry in the park was 25%, while others did not respond to this question.

Result of the analysis of interview held with the staff of NGO

Oral formal interview was conducted for the staff of NCF (Environmental NGO) as the organization designate or representative assigned to monitor Osse River Park Project. Result of the quantitative analysis of the interview is revealing. This was complemented by information received from members of NECOR (a community based NGO registered with Ondo State Government). While NECOR involved in community sensitization programmes like celebration of World Environment Day, International Day for Biodiversity and Tree planting Day, NCF on the other hand involved in various capacities as rated thus provision of environmental education, community sensitization and public awareness (45-50%), stakeholders' relation, engagement, integration (25%), funds raising (5-10%) and protection and surveillance (25-30%). Involvement and participation of the host communities in conservation and management of the park was considered to be very low at present (20%). Factors responsible for low participation and involvement of the host communities are ranked in order of priority to include lack of financial assistance/empowerment to improve the livelihood of the host communities to Osse River Park (25%), failure of the government to constitute an independent management unit to run the affairs of the park (13%), absence of external funding from international and local donors (13%), wrong government approach to the management of the park (top down approach rather than bottom top approach) (13%), lack of intensive conservation education (13%), nonexistence of legislation rules from the state House of Assembly to guide in the management of the park (9%), unavailability of management plan for the park (7%) and improper integration of the host communities in the planning, implementation and evaluation of the park (7%). In order to ascertain authenticity of the result obtained from the interview held with the staff of NCF consent of the organization was sought after with a promise that copy of this research will be made available.

DISCUSSION

Demographic characteristic of respondents and implication on biodiversity conservation

Greater percentage of respondents are male (56.3%), this support the findings of Federal Republic of Nigeria Official Gazette (FRNOG, 2009), that reported the population of Ose Local Government Area as 144,139 with male constituting the highest percentage of 50.73%. Findings from literatures revealed that to conserve biodiversity, there is need to understand and expose gender-differentiated biodiversity practices, gendered knowledge acquisition and usage (United Nation Millennium Goal, 2008; European Union (EU), 2015). The authors opined that projects integrating gender dimensions generate superior results. Gender considerations are not solely a women's issue, it transcend all other demographic characteristics in a society; and this outlook could yield advantages for whole communities and benefit both sexes. In depth understanding of occupational characteristics of the people surrounding the proposed park will assist the management on the type of projects that will be designed to meet their social economic needs. Since larger percentage (55%) of the respondents engaged in subsistence farming, it is expedient to promote and encourage sustainable farming practices among the people in the host communities. Rather than embarking on arrest and enforcement of people to vacate the encroached area of the park the people can be trained on modern techniques of farming supported with agricultural inputs such as improved or hybrid crops and government should introduce sustainable land use practice in the buffer zone area of the park. Practice of agroforestry system provides a different land use option, compared with traditional arable and forestry systems since it allows cultivation of trees and agricultural crops in intimate combination with one another either in temporal or spatial arrangement (Kabwe et al., 2009). Agroforestry system such as taungya farming can be promoted as a sustainable land use practice that allows farmers to cultivate perennial crops such as banana/plantain either in spatial or temporal sequence with the trees. Agro-forestry makes use of the complementarily between trees and crops, so that the available resources can be more effectively exploited. It is a practice that respects the environment and has both ecological and economic advantage. Buffer zone of the park can support practice of agroforestry system whereby arable crops can be cultivated to meet the social and economic needs of the people. Another advantage of agroforestry is that it allows subsistence as well as commercial farming. This forms part of the basis for the formulation of buffer zone initiative across protected areas in some Asia countries like Nepal and Bangladesh (Sharma and Yonzon, 2005; Sharma et al., 2005). A buffer zone is a designated area surrounding a protected area within which the use of forests by local communities is allowed in order to support their gainful efforts in biodiversity conservation. It is aimed at minimizing adverse human impacts on protected areas by meeting livelihoods needs of local communities without interference with the core zone. Encroachment and all other form of anthropogenic activities being experienced in Ose River Park is not peculiar to this area alone, it is a global problem facing protected areas. As a response to declining land productivity, farmers open up forests to expand to new areas and this has led to loss of extensive forests and subsequent land degradation (Kabwe et al., 2009). According to Spears et al. (1994), natural forests throughout the developing world have been depleted and degraded, local populations have increasingly turned to remnant patches of open woodlands, forest fallows and other farming systems for supplying their essential forest product needs and for inputs required in maintaining agricultural productivity. Conceptual framework to guide efforts at increasing crop production, involving the local communities in conservation and at the same time reducing environmental consequence of agriculture practice is the antidote. FAO (2013) emphasized that millions of people could escape poverty, hunger and environmental degradation if countries put more effort into promoting agroforestry, an integrated approach combining trees with crops or livestock production benefits. Other demographic characteristics of the host communities that should be considered for sustainable development of the area to be achieved include the level of education of the people. Since a small number (6.2%) of the population had no formal education, exposing them to training on modern and mechanized view of forest conservation and management will not be difficult. Training and workshop to improve their skill in small scale enterprise such as handling, domestication and management of wild animals and indigenous plants, apiculture, mechanized farming, tour operators, park interpreters, caterers and waiters should be provided as means of generating employment for the teeming population of the youth representing 29.5 to 31.5% of the population. Adeyemo and Oladeji (2013) opined the high literate level in a community as is an impetus for other sustainable practice like ecotourism to thrive.

Stakeholders' participation and involvement in biodiversity conservation

International best practice scenarios have shown that tripartite partnership involving government, the private sector, and local communities work best in conserving biodiversity (Spenceley, 2003). It was observed that despite high level of awareness being created by the Government and NGOs on biodiversity conservation education (62%) and inputs in form of tree seedlings (20%) relatively low percentage of the respondents (36%) engaged in biodiversity *ex-situ* conservation practices like tree planting (23%) and domestication of wild animals (13%). The percentage of those participating in park management was equally relatively low (9%). While large percentage of the respondents (64%) indicated that they did not engage in any biodiversity conservation practices. This calls for serious consideration especially if the objectives of the park and ongoing reformation and transformation aimed at enlisting area as a park are to be realized. In as much as development of ecotourism practice is part of the objectives of establishing the park, there is need to encourage conservation of its rich ecotourism potentials. Development of the rich ecotourism resources in the park will contribute immensely to the social and economic livelihood of the surrounding communities (Oladeji and Kayode, 2013). Local stakeholders' participation has been identified as a vehicle through which successful ecotourism can be achieved (Epler, 2002). Efforts of the government and NGO in sensitizing the community on the need to engage in biodiversity conservation notwithstanding the resultant effect of this act should be reflected in attitudinal changes among the locals on the value attached to biodiversity resources within their reach, hence their contributions cannot be ignored in the integration process. Apart from tree planting and domestication of few species of animals which are *ex-situ* conservation practices, other sustainable *in-situ* conservation practices like construction of park structures for recreation and relaxation, establishment of nursery care for shrubs or trees, habitat restoration, large-scale adoption of renewable energy technologies should be inculcated in these communities. This calls for orientation on the value attached to these resources. The people needed to be educated that apart from local advantages of *ex-situ* conservation through planting of economic trees and domestication of animals in meeting their social and economic needs, there are equally significant global benefits or value chains like attracting foreign visitors that could generate tourist dollars with the active participation of indigenous peoples. One of the global benefits is that active participation and involvement of local communities will promote development of ecotourism industry. It has been observed that development of ecotourism industry has brought the promise of achieving conservation goals, improving the well-being of local communities and generating new business, promising a rare win-win-win situation (Drumm and Moore, 2002). If ecotourism industry is embraced within the local communities, Strasdas (2002) and WTO (2002a) opined that it will have positive effect through creating job opportunities to the local people. Promotion of ecotourism therefore is considered as a way of meeting one of the needs of the local communities in provision of employment.

Management approach towards conservation of Osse River Park

Traditional approaches to park management through law enforcement have been unable to balance the competitive objectives of conserving biodiversity (Wells and Brandon, 1992). In order to engage greater percentage of the locals in the management of Osse River Park, there is need for a shift of paradigm from the present management strategy where the state government through its ministry control absolutely the management of the park. Failure of the government to constitute an independent management unit to run the affairs of the park (13%) was rated second by the staff of NCF as part of the factors responsible for low participation and involvement of the locals in conserving the park. This approach has social and economic implications whereby local dwellers are being arrested and prosecuted for various offences like clearing and farming in the forest, while government is taking all the proceeds or revenue from the park. Thus, the locals felt cheated as they are deny of their means of livelihoods and loss of control on their naturally endowed resources. This explains the reason why change in the management approach to conservation (8%) was part of suggestion for increase participation of local communities in conservation. Traditional paradigm has since been abolished and therefore should no longer be a practice if success is to be achieved in conserving biodiversity resources in Osse River Park. In contrast to the “traditional paradigm”, in which protected areas were managed by the central government without external input, the “new paradigm” emphasizes cooperation in the governance of protected areas. Moreover, local communities should not be passive recipients of top-down guidelines, directives, and prohibitions. Rather, they should be considered as economic and cultural beneficiaries of protected areas as well as active partners. As a result, traditional management of protected areas dominated by natural scientists is gradually being replaced by socio political processes requiring consultations, sensitivity, and astute judgment (Phillips, 2003). A change in the management approach from top bottom approach to bottom top approach constitute 13% as part of suggestion by the NCF for improve participation of the locals. Rather than taking stiff measures government should create opportunity for the locals to benefit in term of employment generation and revenue earning through capacity building and training. Skidmore et al. (2006) noted that local community should not be forced, but rather be given opportunity to participate and involve in projects which affect their lives. Such an approach upheld the basic rights and a fundamental principle of democracy. Organizing the people into groups facilitate group discussions, dialogue and equal participation of the stakeholders. MacDonald and Service (2007) hold that the task of designing modern, crosscutting, transparent, evidence-based interdisciplinary decision making is not only conceptually challenging, but also necessitates a huge increase in local capacity for democracy and decision making.

According to Child (2004) by changing the question of ‘who’ park conservation is for from global to local, we also radically alter the question of ‘what’ national parks are for. The author opined that park agencies had so many demands they did not know what to focus on and at the end nothing is ever being achieved. The host communities understand themselves better, they know their plight, social and economic needs, and hence, they are in better position to plan, manage to address these through the available resources in their domain. If development of ecotourism industry is to be considered as part of the aims and objectives of establishing National Park in Nigeria, then there is need to give the locals the opportunity to plan, manage and administer the proceeds from this enterprise. Integrated Natural Resource Management approach will facilitate these opportunities. Presently it is the government of Ondo State through the state Ministry of Agriculture and Natural resources that is managing the park, thus proceeds from the park goes to the government, this idea can be regarded as ‘winner takes all’ .

Research studies have indicated that motivation for participation increase when the locals are involved in the management of the revenue from the park. According to Bookbinder et al. (1998), to foster greater local support for biodiversity conservation in Royal Chitwan Park, Nepal a bylaw was enacted in February 1996 decreeing that 50% of the park entry fee and a portion of concessionaires taxes must be dispensed to the local communities affected by park protection policies. The authors emphasized that prior to this provision, all park revenues was diverted from RCNP and local economy to the Ministry of Finance with only a small fraction of the money being reinvested into the park and no revenue was distributed to the local community. Now, there is a legal mechanism to distribute ecotourism revenue to the local village group. According to the staff of NCF, Ondo State House of Assembly should enact laws guiding the management of the park which should include among other things the sharing of the proceeds from the park in such a way that the locals will benefit from it.

Forest user group(s) participation in conservation management

Forest user groups refer to group of people in a community involve in the harvest, consumption, conservation and management of forest products like wild animals, leaves, fruits, seeds and plants of medicinal values (Richards et al., 1999; Crystal et al., 2013). Absence of this category of people as indicated by the respondents and the key informants within the communities adjoining Ose River Park calls for serious attention in the quest to achieve its sustainable biodiversity conservation and management. This has serious implication as observed by Crystal et al. (2013) and stated thus (1) It means there is lack of transparent structure whereby government and NGO regularly inform communities about forest management issues and activities, (2) It also connote that there is lack of effective communication mechanisms to promote two-way communication about forest management between communities, government and forest managers, (3) Participation management plans are not developed with involvement and participation of local communities, and (4) Communities have no adequate capacity to effectively participate in forest management planning and implementation. To address these issues raised various community forest users such as farmers, charcoal/firewood collectors and traders, hunters, timber group, honey tapper/bush meat sellers, gatherer of edible fruits/seeds and fishermen should be identified and constituted as groups no matter the size or the number of members in each group. Skidmore et al. (2006) emphasized a 1% solution as a way to reach the locals at the grass root level in order to involve them to participate in governance. Skidmore et al. (2006) opined that choosing relatively few people to participate in formal governance does not mean we should discard the ambition of community participation, but rather that we should recast it. Marten and Suutari (2006) opined that what supports communities to be involved in conservation is encouragement and inspiration, skills and knowledge, contacts and networks (for example being asked to be involved by someone they known), sufficient resources for task, opportunities for involvement, two way communication, successes and acknowledgement. The NGOs can assist in constituting these groups, monitor and evaluate the performance of each group. Child (2004) emphasized that complexity of organizing remote rural communities into common property management units could be a challenge, giving rise to fascinating experimentation and literature on governance, organizational and political theory but the gains can be immeasurable. The author opined that evidence is accumulating that community conservation management of wildlife at village level is an order of magnitude more powerful in terms of transparency, involvement, democratization, reduced corruption and misappropriation, and the number of projects built, than channeling benefits to higher-level representational committees, the want of most development projects.

Capacity building and training

Another strategy to achieve participation and involvement of host community as a stakeholder in conservation is by providing capacity building and training. NGO should be involved in capacity building so as to strengthening the abilities of the host communities of Osse River Park to be effective and efficient in the use of the biodiversity resources. Domestication of wild animal such as rearing of grasscutter/giant rat and snailry (13%) as recorded among the respondents (Table 5) are regarded as novel biodiversity conservation practice. According to Smout et al. (2000) capacity building through skill training and confidence building can be a key ingredient in motivating and mobilizing different sections of the community to participate in the management of a project. This task rest on the NGOs in providing training for the locals in the area of alternative economic activities like domestication of wild animals like grasscutter, bee keeping and snail multiplication. Training can also be provided to improve their skill in tourism, hospitality and catering services. This is a serious challenge to all the NGOs in Ondo-State especially those that have been recognized as registered with the State Ministry of Environment or Ministry of Natural resources.

Environmental education and awareness creation

Only 20 and 10% of the respondents in the local communities identified provision of inputs and intensification of conservation education as needing attention, respectively. There is need to develop a synergy between the Government Ministries and NGO in the area of environmental conservation education and awareness creation. For instance, NCF prepared a blueprint for the development of conservation education in Ifon Forest Reserve as a way to reach the communities and educate them on the importance of biodiversity conservation (NCF, 2008). According to Nathaniel and Nathaniel (2013), it brings to some comfort to know that some governmental and non-governmental organizations in Nigeria in collaboration with the United Nations Environmental Programme (UNEP) and the World Wild Fund (WWF) and several other agencies have embarked on programmes to protect and preserve the nation's biodiversity.

Despite all these, the areas of participation of the locals in biodiversity conservation and the percentage of people involve in park management activities are very low. The reason is that biodiversity conservation education through the media or any form and provision of input such as seedlings for annual tree planting exercise are considered as political jamboree that have failed to address their social economic needs. Suffice to say that intensive environmental education is creating awareness among the locals but it has failed to awaken their consciousness in lending their support to biodiversity conservation and management activities, unless the socioeconomic needs of the people are met.

Despite the level of awareness being created by both the government and NGOs, there is increasing anthropogenic activities being recorded. The underline fact is that the people considered biodiversity as a mean to an end. Balmford et al. (2002) reported that biodiversity is fundamental for current, future, social and economic livelihood and human derive benefit from biodiversity have influence on ecological, cultural and social impact. According to Child (2004), the World Bank's cutting-edge literature (World Bank, 2002) advocates the theory that the best way to encourage development is to provide poor people with truly discretionary financing, the Community Based Natural Resources Management (CBNRM) movement has already experimented with cash distribution and wildlife dividends and show just how powerful fiscal devolution and discretionary financing can be. Financial empowerment will enable the communities to operate and own alternative livelihood projects, thus, heartening them to participate and involve in biodiversity conservation activities being initiated by government and NGO toward the development of Osse River Park. The implication of this is that there is need for increased financing from the present 5 to 10% NCF/NGO's input in fund raising and the government's commitment in finance from 25% (Table 9) to 70 to 80% or more.

Preparation of management plan

Availability of well written management plan is a necessity in the ongoing efforts at developing Osse River Park. Management plan is a very comprehensive document; it can be regarded as a blue print containing information on the aims and objectives of conserving the park, inventory of fauna, flora and cultural resources in the park, social, economic and demographic information of the adjoining communities. The management plan also contain information on the land use practice and human settlement, the management problems and challenges, boundary demarcation, road development, culture and tradition, and alternative economic activities to sustain the locals in the course of conservation, etc (Afolayan et al., 1997). This blue print is an aftermath of a comprehensive research undertaken over a period of 2 to 3 years through integrated and consortium approach. Experts are drawn from various fields of natural resources management, biodiversity conservation, community development, sociology, ecology, economists, environmentalists', etc. Lack of management plan as noted in this research work, therefore raises so many questions and this might create imbalance in the integration process. The resultant effect is total disintegration, lack of support and cooperation among the stakeholders. Osse River Park is in transition period from forest reserve of many years to a park. This might generate confusion and conflict among the locals and other stakeholders unless a management plan is prepared where the roles of all the stakeholders are clearly spell out. For instance, while forest reserve permits the local communities to harvest and collect forest and non-forest products for their subsistence, such activities are strictly prohibited in the park. According to FAO (2003), forest reservation was usually done in consonance with the local communities, who were authorized to continue their former uses of the forests, so far as such practices did not contravene the management of the forest for timber production. In contrary, park is a protected area managed for ecosystem conservation and recreation, they fall under Category II of protected area with clear boundaries drawn sufficiently to contain one or more entire ecosystem which are not subject to material modification by human exploitation or occupation (IUCN/WCMC, 1994). The imbalance between the stakeholders can be addressed by preparing a management plan thereby facilitating cooperation, mutual understanding and participation among the stakeholders in the integration process.

Conclusion

Despite financial and materials input of both the government and NGO environmental education and conservation of Osse River Park, the level of participation and involvement of the host communities in conservation and management of the park were observed to be very low. Increasing efforts are needed in the area of capacity building and training, employment and providing alternative economic activities to the support zone communities. The need for a change of paradigm in the management of the park was also emphasized. All these can be achieved through participatory approach in natural resources management. This approach will facilitate cooperation, support, involvement and participation among the stakeholders. Also, government and NGOs should increase their financial contribution and capacity building respectively towards the park and its host communities. Finally, the development of ecotourism practices as part of integration process will go a long way in addressing some of the imbalance observed in this research work.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Spatial analysis of soil physical attributes from a degraded area under different types of management

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The objective of this work was to analyze the spatial variability of soil aggregates, porosity and density under five different land-uses and management conditions (degraded substrate - SD; degraded substrate with sewage sludge and *Eucalyptus* crop - SDLE; soil under pasture SP; *capoeira* under regeneration - SR; and soil under *cerrado* - SC). Total porosity ($m^3.m^{-3}$) and density (Mg m^{-3}) of the soil; the mean weight diameter (MWD, mm) of the aggregates; and the percentage of aggregates resistant to rainfall were evaluated. The date of soil was analyzed with descriptive statistics for initial exploration and geostatistics, to analyze the spatial variability. There was spatial dependency and the parameter adjust range varied from 8 to 12 m under the treatments SD and SR for the aggregates and SR for macroporosity, total porosity and soil density. There was spatial dependency also under SP, for the aggregates, microporosity, and total porosity; under SC, for the aggregates; and under SDLE, for microporosity. Soil data with spatial dependence in the field were characterized both by high and low values in the same area. Therefore it is not adequate to consider these areas as homogeneous for future experiments and agricultural activities.

Key words: Spatial variability, soil aggregates, geostatistics.

INTRODUCTION

At the Northwest region of the Brazilian state of São Paulo, large pasture areas are used for bovine cattle breeding and often show a history of degradation of their physical, chemical and biological soil features. The same

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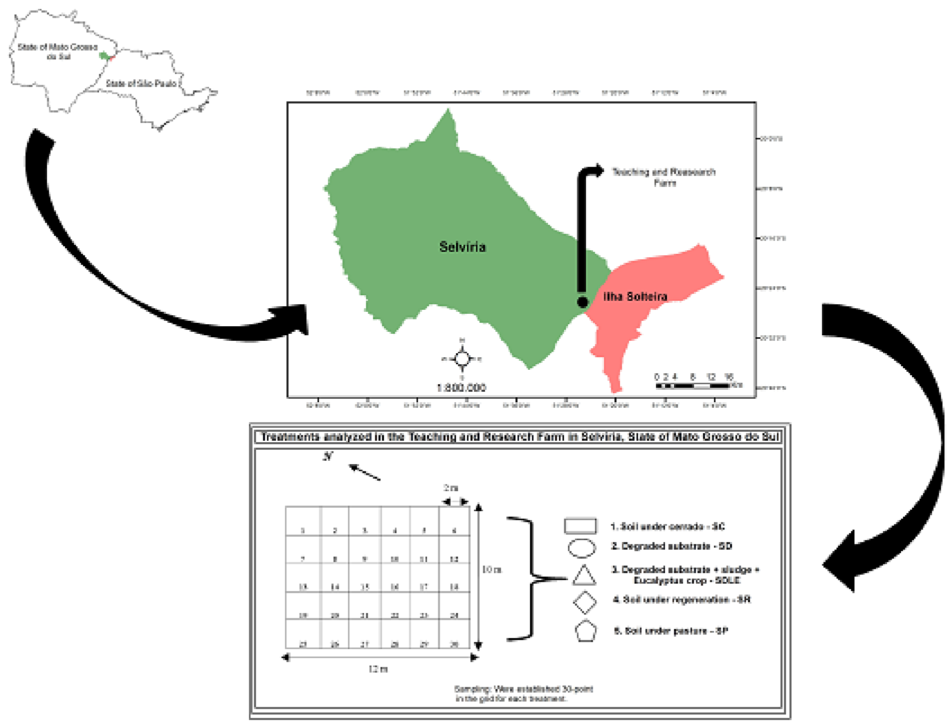


Figure 1. Location of the study area.

goes for other uses which are poorly carried, such as the building of fills, cut-offs for the construction of roads, and mining activities, which cause the removal of thick soil layers, and consequently increase the deterioration of the system and cause stronger impacts to the environment.

This study has given special attention to the changes in physical soil attributes caused by moving large and thick volumes of soil for the construction of hydroelectric power dams (Alves et al., 2012). The construction of the hydroelectric power station of Ilha Solteira (SP, Brazil), in 1967, required excavating over 8 m off the left margin of the Paraná River (at the city of Selvíria, MS, Brazil), and left a compacted and impoverished substrate with scarce, low-height vegetation. Neighboring areas, which are also susceptible to the traffic of heavy machinery, were transformed into pastures or natural secondary vegetation (*capoeira*). A small part of the area, contiguous to the remainder Experimental Farms located in Ilha Solteira, SP, remained intact, and its natural *cerrado* vegetation was maintained.

The analysis of physical attributes of the afore-mentioned management systems comes from knowledge of the variability of soil attributes across space and time (Grego and Vieira, 2005). According to Andrade et al. (2005), modeling the spatial dependency of soil variables, allows estimation points in unsampled locations, thus making it possible to produce maps and zonings of the variable under study with better accuracy. For that purpose, geostatistics, more specifically semivariogram analysis, is the tool mostly used to characterize spatial variability.

Another aspect analyzed in this study was soil aggregation. Carvalho et al. (2002) calls attention to the direction given in the study of aggregation of soil that mostly relate to the determination of the distribution of pore size and aggregates. Thus, it is believed that studies that verify the spatial variability of soil aggregation become important to the management of agricultural practices, once soil aggregation attributes are strongly associated with soil quality (Grego and Vieira, 2005).

The hypothesis in this study is that taking spatial variations into consideration when analyzing the soil physical attributes enhances the knowledge on the use of the soils across the whole study area. Thus, the objective in this work was to analyze the spatial variability of the structure (soil aggregates), porosity (macro and micro) and density of the soil under different use conditions.

MATERIAL AND METHODS

Study area

The study area is located within Universidade Estadual Paulista's (Unesp) experimental farm at Selvíria, Mato Grosso do Sul state, Brazil (51°22' West, 20°22' South – Figure 1), at a 355 m above sea level and a plain to slightly sloped relief. The Climate of the region

Table 1. Particle size characterization of the soil at the 0.00–0.20-m layer in the surroundings of the hydroelectric power station of Ilha Solteira (SP, Brazil), determined in 2004.

Treatments	Clay	Silt	Thick sand	Thin sand	Total sand
	---------------------------------- g kg^{-1} ------------------------------				
SD	221	28	405	346	751
SDLE	225	39	360	376	735
SR	216	42	338	403	741
SP	221	34	458	286	744
SC	177	39	408	375	784

SD, degraded soil with no anthropic intervention; SDLE, degraded soil treated with sewage sludge and planted with *Eucalyptus*; SR, degraded soil with *capoeira* under natural recovery; SP, soil with pasture replacing natural vegetation; SC, soil under native vegetation (*cerrado*). Clay, < 0.002 mm (pipette method); Silt, 0.053 – 0.002 mm; Thick sand, 2.000 – 0.210 mm; Thin sand, 0.210 – 0.053 mm; Total sand, 2.000 – 0.053 mm (Camargo et al., 2009).

is Aw, according to the Köppen classification system.

During the year, according to Demattê (1980), the average regional temperature is 23.7°C, with an average of 25.7°C during the warmest months (January and February) and of 20.6°C during the coldest months (June and July). The rainfall regime present an average annual rainfall rate of 1,300 mm, and the average relative humidity varies from 60 to 80% during the rainy months (from October to March), and from 50 to 60% during the dry months.

The experimental area is located at former construction sites of the hydroelectric power station of Ilha Solteira (SP, Brazil). Therefore, since 1967, the area has undergone deep excavations, which reached up to an estimated height of approximately 8 m at some spots. As a consequence, the soil became impoverished and compacted.

Some of the degraded plots were left as natural secondary vegetation (capoeira), others were kept preserved, with no further excavation, and part of the native *cerrado* vegetation was transformed into pasture. These land-use situations have been monitored over time with the aim of evaluating several processes related to their environmental recovery, thus becoming study sites for professors and students, among them are Colodro and Espindola (2006), Campos and Alves (2008), and Rosa et al. (2014).

Sampling

The soil samplings were made in July, 2004. Soil uses and managements were analyzed across five treatments employed in 12 x 10 m plots:

- Degraded soil, decapitated in 1967, with no traces of regeneration of its plant cover and with no treatments to promote recovery.
- Degraded soil treated with a single rate of application (60 Mg ha^{-1}) of sewage sludge in August 2003, and planted with *Eucalyptus*.
- Degraded soil with presence of plant cover (*capoeira*) naturally recovered since 1967.
- Soil with pasture, with no use of chemical supplies, formed onto a natural plant cover (*cerrado*) since 1993.

Soil covered by native *cerrado*. In this area the primitive soil is an Oxisol (Soil Survey Staff, 2010), corresponding to a Latossolo Vermelho by the Brazilian classification system (Santos et al., 2013), of medium texture, and very deep and rich in Fe and Al oxyhydroxides (Carvalho et al., 2015).

For the particle size analysis, five soil samples, one for each experimental plot, were sampled using a 30-point grid (Table 1) at 0.00 to 0.20 m layer. These areas exhibit two texture classes (Demattê, 1980; Santos et al., 2013),which showed less expressive maximum differences in total clay and total sand content (≤ 48.50 and ≤ 48.23 g kg^{-1}, respectively) under native soil in comparison to the other treatments.

The structure of the soils was analyzed using the Kemper and Chepil (1965) method, which evaluates the stability of soil aggregates and the mean weight diameters (MWD's) by means of a mechanical agitator containing a set of sieves with different diameters. Thus, the 30 samples were analyzed at 0.00 to 0.20 m depth using duplicate samples of 25 g each, which were sieved in 9.52, 7.93, 6.35, 4.00, 2.00, 1.00, 0.50 and 0.50 mm mesh sieves.

The soil aggregates were also evaluated using the rainfall-simulation method, in which the hydraulic load used was enough to maintain constant dripping (Boyle-Mariotte's principle), as described by Roth (1985). This author verified simulator as the model used in this study, where precipitation of 64 mm/h represent a kinetic energy equivalent of about 60 to 80% of energy of the natural rainfall.

For the rainfall-simulation method, duplicates of 3 g of soil aggregates were sampled for each treatment, and an average rainfall of 60 mm h^{-1} was applied onto them during 20 m to produce three classes of aggregate sizes: 9.52 to 6.35, 9.52 to 4.00 and 9.52 to 2.00 mm. Then, the aggregates were transferred to aluminium crucibles with the aid of a wash bottle which were dried in the oven (105°C). The relative amount of stable aggregates under simulated rainfall (SAUSR) was obtained after reaching constant weight.

The density of the samples was determined according to Blake and Hartge (1986), and the porosity (microporosity was obtained using 6-kPa tension) according to Camargo et al. (2009). For each of the treatments, the soil samples were obtained using 100 cm^3 volume rings and collected using 30 point grids at an equal distance of 2 m and at 0.00 to 0.10 m depth.

Statistical analyses

For an exploratory analysis of the data, descriptive statistics calculations were performed (mean, variance, coefficient of variation, skewness and kurtosis) using the STAT program (Vieira et al., 2002). Coefficients of skewness and kurtosis with values near zero (0) indicate data with normal distribution. If the data do not show normal distribution, some kind of transformation may be applied, such as logarithmic transformation. Normality is necessary when the hypothesis used is data randomness, to which classical statistics is applied. However, for geostatistics non-normality is not limiting for further analysis.

To verify if there was spatial dependence among the variables, geostatistical analysis was employed (Vieira, 2000; Vieira et al., 2008). The semivariograms were created based on the intrinsic stationarity assumption and the semivariance calculation γ(h) was estimated using Equation 1:

$$\gamma^*(h) = \frac{1}{2\,N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

N (h) is the number of pairs of the measured Z(xi), Z(xi + h) values, separated by an h vector. According to Vieira (2000), it is expected that measurements taken near one another are more similar than those separated by large distances, that is, that the value of γ(h) increases along a distance of h, up to a maximum value, at which it stabilizes at a level that corresponds to the limit of the spatial dependence distance, the range. Measurements taken beyond the range will show random distribution.

The semivariograms showed spatial dependence which was fitted using a mathematical model. Most of the semivariograms were fitted to the spherical model, whereas some fitted to the gaussian model (Equations 2 and 3). The models of the semivariograms were chosen according to the distribution of their points and were validated from the models adjusted according to Vieira et al. (2014). This method allowed the obtaining of Determination Coefficient (R^2) and the Degree of Dependency (RD):

$$\gamma(h) = C_0 + C_1 \left[\frac{3}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^3\right];0 \quad 0 < h < a \text{ ou}$$
$$\gamma(h) = C_0 + C_1 \quad h > a \quad (2)$$

$$\gamma(h) = C_0 + C_1 \left[1 - \exp\left(-3\left(\frac{h}{a}\right)^2\right)\right] \quad 0 < h < d \quad (3)$$

The semivariogram parameters were defined: C_0 = nugget effect, which is the value of γ (h). When h = 0; a = range, which is the distance beyond which γ (h) remains rather constant after increasing along with h; $C_0 + C_1$ = sill, the value of γ (h) beyond the range that approaches data variance; and C_1 = structural variance, that is, the difference between the sill and the nugget effect.

The spatial dependence ratio was also calculated (RD), which is the percentage proportion between the structural variance (C_1) and the sill ($C_0 + C_1$), in Equation 4. According to Zimback (2001), (a) strong dependence > 75% (b) moderate dependence from 26 to 75% and (c) weak dependence < 25%.

$$RD = \left(\frac{C_1}{C_0 + C_1}\right) \cdot 100 \quad (4)$$

The semivariograms' adjustment parameters (C_0, C_1, a) were obtained for the soil variables which showed spatial dependence. In these cases, the neighboring values will be so similar which will be possible to estimate values using kriging for any place, where variable has not been measured.

According to Vieira et al. (2002), the method estimates values using estimation conditions with no trend and with minimum variance towards the known values, that is, with minimum variance (Equation 5):

$$\sum_{j=1}^{N} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0),\ i=1.N \qquad \sum_{j=1}^{N} \lambda_j = 1 \quad (5)$$

Where $\gamma(x_i, x_j)$ is the semivariance estimated using the model fitted to the semivariogram, which corresponds to the distance between the points located at x_i and x_j positions; $\gamma(x_i, x_0)$ is the semivariance that corresponds to the distance between the points located at x_i and x_0 positions; λ–weight values and μ is a Lagrange multiplier. Using the λ_i values, (Z) can be estimated in the sampled space for any x_0 position. Also, using the estimated values (Equation 6), isoline maps based on the geographic coordinate using the Golden Software (1999) software can be built.

$$Z(x_0) = \sum_{i=1}^{N} \lambda_i Z(x_i) \quad (6)$$

RESULTS AND DISCUSSIONS

Through the aggregate stability analysis (Table 2), MWD's revealed aggregation states in direct proportion to the degradation degree of each treatment. Thus, soils which had no layers removed (soil under *cerrado* and soil with pasture) are composed by a different group of aggregates, when compared to the remaining treatments, which showed degraded soils (degraded substrate, degraded substrate + sludge + *Eucalyptus*, and soil developing natural secondary vegetation (capoeira).

This situation may be expressed by MWD's of the aggregates obtained: 4.70 mm for soil under *cerrado*; 1.97 mm for soil with pasture; 1.50 mm for soil recovered with *capoeira*; 1.08 mm for degraded substrate with application of sludge and *Eucalyptus* crop; and 0.83 mm for degraded substrate (Table 2). According to Kiehl (1979), low stability is connected with a MWD index lower than 0.5 mm, above which the aggregation index is considered resistant to raveling and dispersion, this help to understand the values obtained in this study for the degradeted areas.

Thus, the most adequate conditions for plant development were those seen on soil aggregates under *cerrado* and pasture. This is because of their capacity in conserving their structure when subjected to the water action. In this sense, in the study of Rodrigues et al. (2007), which was carried out at experimental farm at the UNESP of Ilha Solteira, the *cerrado* and pasture MWD's also showed high indices when compared to the farm's degraded soils.

Table 2. Average values, variance, coefficient of variation (C.V.), skewness and kurtosis for the mean weight diameter (MWD) and stable aggregates under simulated rainfall (SAUSR).

Soil uses	Mean	Variance	C.V.	Skewness	Kurtosis
			Aggregates' MWD (mm)		
SD	0.83	0.23	57.78	1.20	0.95
SDLE	1.08	0.25	46.90	1.93	3.45
SR	1.50	0.17	27.76	-0.02	1.25
SP	1.97	0.14	18.96	0.48	0.78
SC	4.70	2.36	32.72	-0.48	-1.46
			SAUSR within 9.52–4.00 mm (%)		
SD	39.00	518.3	58.38	0.34	-0.44
SDLE	44.38	773.3	62.65	-0.14	-1.44
SR	15.25	142.4	78.24	1.16	1.20
SP	15.91	125.7	70.48	0.30	-0.70
SC	18.44	158.6	68.29	2.27	7.81

SD, degraded soil with no anthropic intervention; SDLE, degraded soil treated with sewage sludge and planted with *Eucalyptus*; SR, degraded soil with *capoeira* under natural recovery; SP, soil with pasture replacing natural vegetation; SC, soil under native vegetation (*cerrado*). Aggregate stability using MWD by Kemper and Chepil (1965) and using simulated rainfall according to Roth (1985) and Carvalho et al. (2015).

Tropical soils are subject to increased erosion and soil organic matter loss, thus studies that evaluate the effects of incorporating organic materials into soil aggregation are important. In this sense, Spaccini et al. (2002) evaluated MWD of aggregates of Ethiopian tropical soils. MWD was higher in forest soil than treated soils (crop residues and manure), regardless of location.

The quality of the structure of a degraded Oxisol was also evaluated by Bonini and Alves (2011) in order to detect its degree of recovery after 17 years of treatment with green fertilizers, chalk, gypsum and grass *Brachiaria*. In this work a higher average MWD value for native *cerrado* plant cover was also obtained, followed by an increase in aggregate size in the treatments featuring an increase in the aforementioned supplies.

The treatment with sludge and *Eucalyptus* cultivation showed a small increase in percentage of aggregates in comparison to the degraded soil with no improvement. It is known, based on the analyses made by Galdos et al. (2004) and Barbosa et al. (2002), that the addition of sludge significantly increases the percentage of organic matter, which consequently increases aggregate stability.

The increase in average MWD values was also detected by Maria et al. (2007) when analyzing a clayed Oxisol subjected to two rates, 10 and 20 Mg ha^{-1}, of sewage sludge. As detected in this and other studies (Baldock and Kay, 1987; Silva and Mielniczuk, 1997; Wohlenberg, et al., 2004) which evaluated the stability of soil aggregates under that same condition, a kind of land cover offers a continuous supply of organic matter produced by root exsudates, by the renovation of the root system, and by the shoots or harvest residues, which cause stronger agglutination of soil particles.

The coefficients of variation for the MWD parameter indicated a strong difference between treatments, especially between SP (18.96%) and SD (57.78%). This is justified by the heterogeneities of the different use and management conditions to which the soils were subjected. In this same area, the soil aggregates in the pasture were strongly different from the other uses and management studied by Rodrigues et al. (2007) and Costa et al. (2014). These and other authors confirm that there is an effect of the permanent pasture root system on the macroaggregate formation process, especially the rhyzosphere, in aggregate formation and stability.

According to the classification proposed by Warrick and Nielsen (1980), the coefficient of variation is classified as low (< 12%), medium (from 12 to 60%) and high (> 60%). Most coefficients of variation detected in this study ranged from medium to high (> 20%) for the variables related to soil aggregates (Table 2), which indicates high variation between the minimum and maximum values. However, in the rainfall simulation method for the detection of soil stability the variation of the coefficients between treatments was low, which mean that the method translates a degree of homogeneity between the treatments.

The proven heterogeneity between the treatments when submitted to the method of stability through of a mechanical agitator with set of sieves, and homogeneity in the method of stability through the simulator-rainfall, can be understood by the particularities that each method presents.

In the stability by mechanical agitator, for example, the samples arranged in the set of sieves were immersed in a cylinder containing water, which provided the filling of the pores of the soil aggregates by the water, and compresses their internal spaces and, consequently, the cohesion between the particles which is overcome, added to that, there is a agitation of the sieves. This type of analysis aims to reproduce the phenomena of concentrated water and flood (Kemper and Chepil, 1965; Kemper and Rosenau, 1986).

In the method of stability of aggregates by simulator-rainfall, soil aggregate samples were not immersed in water before being submitted to dripping and agitation, which may explain a low rate of soil loss during the application of this method and, consequently, a low coefficient of variation between treatments. In accordance with the studies that used this method, its objective is to reproduce the action of the raindrops on the aggregates of the soil (Meester and Jungerius, 1978; Benito Rueda and Diaz-Fierros Viqueira, 1989).

Because of inadequate management arid, the Spanish Mediterranean has undergone desertification. Thus, the stability of soil aggregates by rainfall simulator was evaluated for these soils. It was verified that stable aggregates increased in the management in which oats straw was introduced to the soil when compared with the "control" (abandoned land), herbicide, plowing and plowing + oats. The authors noted that two main factors protect soil against erosion: vegetation cover, which can reduce rainfall energy and aggregate stability, strongly related to soil organic matter content (García-Orenes et al., 2012).

Brazilian Oxisols of the Cerrado biome with unsustainable management have also processes similar to desertification that justify the use of practices such as those mentioned in this study. Other statistical parameters were tested for skewness and kurtosis. It was verified that most treatments showed compatible with the normal distribution (values near 0), except for the MWD under SDLE, and the aggregate percentage under SC. However, according to Souza et al. (2014), geostatistics, are more important than normality because the semivariograms shows well-defined sills, thus enabling the hypothesis of the neighboring points which show more similarity than points further from one another.

Porosity and density are soil physical attributes which enable inferring soil-water-plant relations, soil compaction state and prospects of root expansion, and therefore are very useful for management plans (Reichert et al., 2007). In this work, as shown in Table 3, the macroporosity average was higher at the native plant cover (*cerrado*) area, followed by the area with a degraded substrate grown with *Eucalyptus* and onto which sewage sludge was applied, which indicates at least an initial recovery of the structural conditions due to the organic matter input, despite the short period (one year) of that management practice. Jorge et al. (1991) also observed an increase in macroporosity in a clayed Oxisol to which 40 or 80 t ha^{-1} of sewage sludge were applied in one single application. The behavior of the soil density (Table 3) suggests that the available land cover has some sort of effect onto soil density, at least within the first 0.10 m. It is interesting that, in absolute values, the density of *Eucalyptus* areas is higher than that of the material under exposed soil and under *cerrado*, which may be associated with higher contents of sand in it (Rodrigues et al., 2007), as shows Table 1.

Soils presenting pastures and *capoeira* reflect the effects of soil compaction to which they were subjected, and showed macroporosity values of 0.19 and 0.17 $m^3.m^{-3}$, respectively. Although grasses favor porosity, a cattle stepping significantly contributes to soil compaction (Courtney and Trudgill, 1984). The degraded substrate, due to its high densification degree, showed the smallest macroporosity value (0.12 $m^3.m^{-3}$), similar to that obtained by Bonini and Alves (2011) for that same area (0.10 $m^3.m^{-3}$).

The microporosity values ranged from 0.24 to 0.27 $m^3.m^{-3}$. Thus, there was no expressive reduction in microporosity, even after the treatments applied at the surface (incorporation of sewage sludge and *Eucalyptus* crops). Moreover, at the soil covered by *cerrado*, which features a rougher texture and a greater supply of organic matter, the values obtained were not much different from those of the degraded substrates.

The soil under *cerrado*, which presents a thicker plant cover, showed the highest total porosity value, 0.53 $m^3.m^{-3}$, in spite of its rougher particle size distribution (Carvalho et al. , 2015), probably due to is high sand content.

Since density is inversely proportional to porosity, the degraded substrate showed the highest value for density among all treatments (1.92 $Mg.m^{-3}$), due to the aforementioned removal of a thick layer of soil followed by its compaction by heavy machinery. The degraded substrate with *Eucalyptus* crop and sludge application showed a reduction in soil density (1.61 $Mg.m^{-3}$), and consequently an increase in macroporosity, which is similar to what was observed by Colodro and Espindola (2006). However, as these authors adequately evaluate, it should be considered that this reduction may have also been caused by the mechanical effect of soil tillage using a rotating hoe, added to the residue's action.

At the same degraded area studied here, Campos and Alves (2008) have observed an improvement in density values, which decreased from 1.68 to 1.48 $Mg.m^{-3}$ after the application of biosolids (sewage sludge). The coefficients of variation for total porosity and soil density showed the smallest values, which are considered average to low (< 20%).

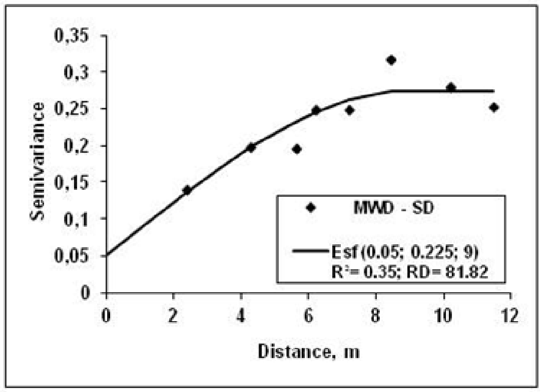
Table 3. Average values, variance, coefficient of variation (C.V.), skewness and kurtosis for soil porosity (macroporosity and microporosity) and density.

Soil uses	Mean	Variance	C.V.	Skewness	Kurtosis
			Macroporosity ($m^3.m^{-3}$)		
SD	0.12	0.0015	32.80	0.51	-0.39
SDLE	0.23	0.0013	15.63	0.40	0.48
SR	0.17	0.0013	21.29	-0.09	-0.42
SP	0.19	0.0010	16.42	0.14	-0.71
SC	0.36	0.0041	17.53	0.95	4.65
			Microporosity ($m^3.m^{-3}$)		
SD	0.24	0.0003	7.66	0.39	0.10
SDLE	0.24	0.0014	15.17	0.29	0.24
SR	0.27	0.0004	7.08	0.04	-0.77
SP	0.25	0.0005	9.07	0.71	0.78
SC	0.17	0.0006	13.79	0.94	1.16
			Total porosity ($m^3.m^{-3}$)		
SD	0.36	0.0015	10.79	-0.10	-1.38
SDLE	0.48	0.0022	9.76	0.66	1.22
SR	0.44	0.0008	6.33	-0.15	-0.82
SP	0.44	0.0009	6.98	0.39	0.97
SC	0.53	0.0033	10.82	1.60	5.36
			Density ($Mg.m^{-3}$)		
SD	1.92	0.0119	5.69	-0.35	-0.34
SDLE	1.61	0.0151	7.63	0.06	-0.68
SR	1.66	0.0076	5.27	-0.15	-0.53
SP	1.68	0.0056	4.46	-0.15	-0.15
SC	1.19	0.0096	8.24	-0.16	-0.50

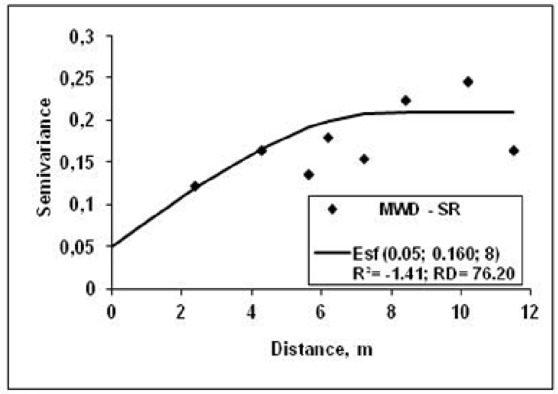
SD, degraded soil with no anthropic intervention; SDLE, degraded soil treated with sewage sludge and planted with *Eucalyptus*; SR, degraded soil with *capoeira* under natural recovery; SP, soil with pasture replacing natural vegetation; SC, soil under native vegetation (*cerrado*). Density (Blake and Hartge, 1986) and porosity (microporosity was obtained under a 6-KPa tension) according to Camargo et al., 2009.

For the variables that showed dependence, with a range between 8 and 12 m, the semivariograms were created and fitted (Figures 2). The remaining attributes showed pure nugget effect, that is, no spatial dependence. Thus, the soil aggregates MWD were spatially dependent under SD, SR, SC and SP, but not under SDLE, which may result from the form of distribution of the sludge within the area, at short distances, and also resulted in discrepant values and hampered the identification of the spatial dependency. Under SD there was also spatial dependence for the percentage of aggregates analyzed using the rain simulator, which may indicate an intrinsic spatial variability of soil that features horizons that are remnants of degradation processes, once spatial dependence was also detected for this treatment during the MWD analysis.

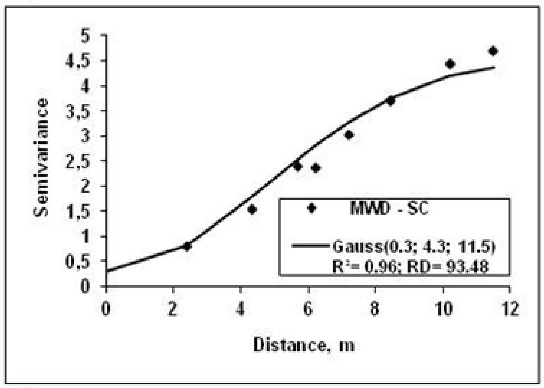
There was spatial dependence for macroporosity under SR, for microporosity under SDLE and SP, for total porosity under SR and SP, and for soil density under SR. SR, where the soil layers was removed were shallower than SD which showed spatial dependence for most of the physical attributes analyzed. This fact may indicate that even when the soil removal is not so deep there is spatial variability due to intrinsic differences to the most superficial horizons. Grego and Vieira (2005) also detected spatial dependence for density and porosity in small plots. Rosa et al. (2014) conducted studies which evaluate the natural regeneration conditions of soils with Cerrado vegetation. The authors, who based their results on physical and chemical parameters, found that the processes of natural regeneration of the Cerrado in degraded areas are relatively more successful than in forest regions. The efficiency in soil recovery under Cerrado makes comprehensible the good results


Semivariance
Distance, m
MWD - SD
Esf (0.05; 0.225; 9)
R²= 0.35; RD= 81.82

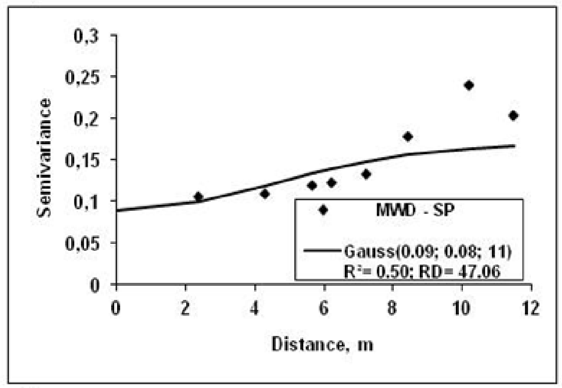
a)


Semivariance
Distance, m
MWD - SR
Esf (0.05; 0.160; 8)
R²= -1.41; RD= 76.20

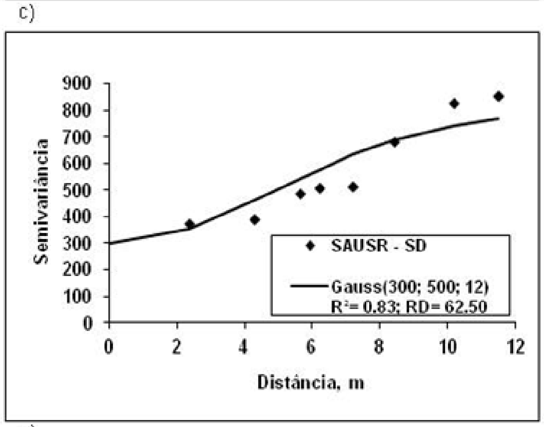
b)


Semivariance
Distance, m
MWD - SC
Gauss(0.3; 4.3; 11.5)
R²= 0.96; RD= 93.48

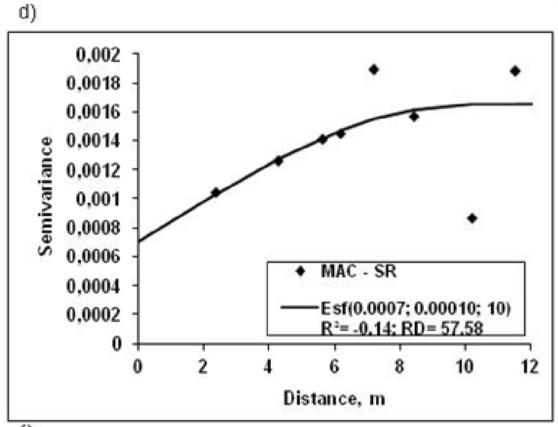
c)


Semivariance
Distance, m
MWD - SP
Gauss(0.09; 0.08; 11)
R²= 0.50; RD= 47.06

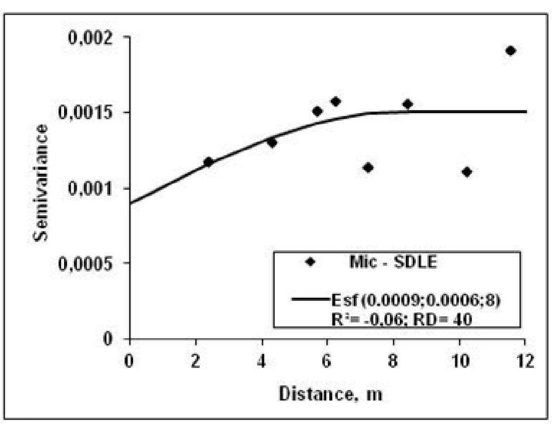
d)


Semivariância
Distância, m
SAUSR - SD
Gauss(300; 500; 12)
R²= 0.83; RD= 62.50

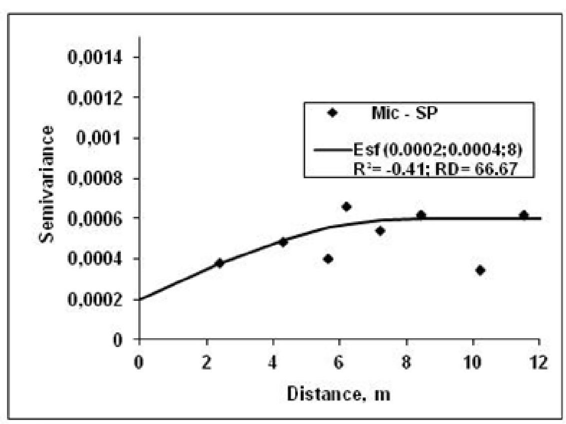
e)


Semivariance
Distance, m
MAC - SR
Esf(0.0007; 0.00010; 10)
R²= -0.14; RD= 57.58

f)


Semivariance
Distance, m
Mic - SDLE
Esf (0.0009;0.0006;8)
R²= -0,06; RD= 40

g)


Semivariance
Distance, m
Mic - SP
Esf (0.0002;0.0004;8)
R²= -0.41; RD= 66.67

h)

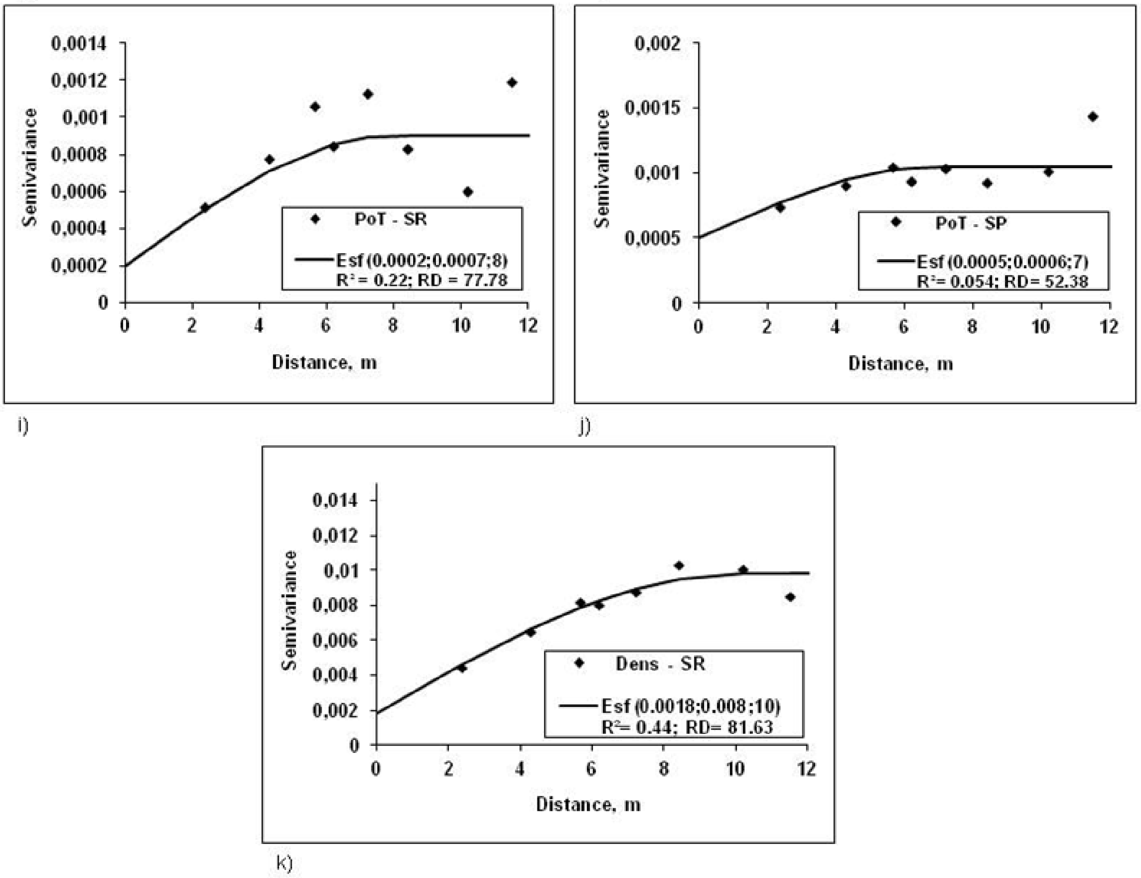


Figure 2. Semivariograms featuring spheric adjustment parameters (Esf (C0; C1; a) of the soil's physical attributes: a) MWD – SD; b) MWD – SR; c) MWD – SC; d) MWD – SP; e) aggregates under simulated rainfall at the 9.52–4.00-mm class; f) macroporosity – SR; g) microporosity – SDLE; h) microporosity – SP; i) total porosity – SR; j) total porosity – SP; and k) density – SR.

achieved in SR treatment in the present study.

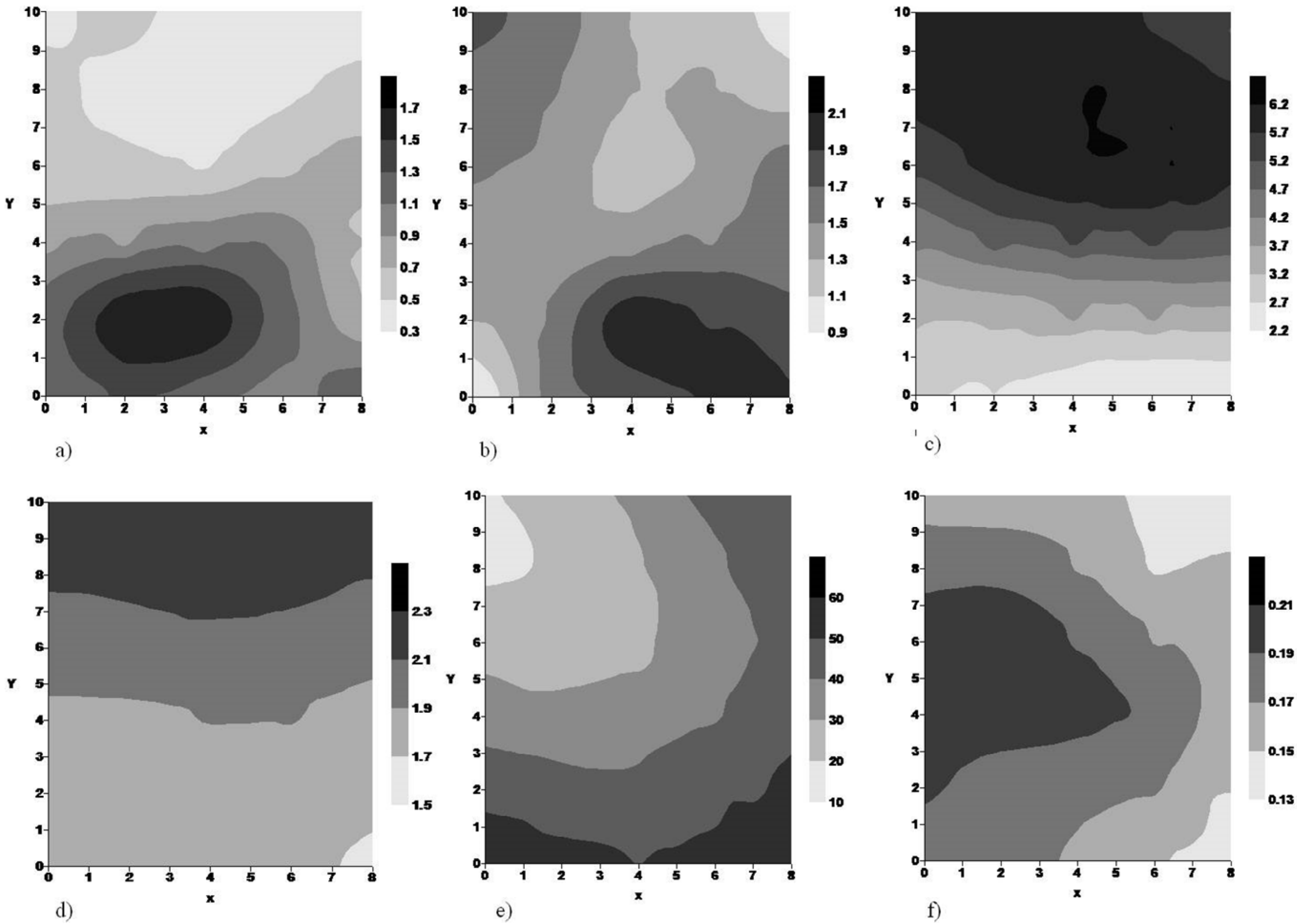
After performing the spatial dependency analysis and obtaining the parameters for the semivariogram, maps were created in variables using values estimated and kriging which are grouped by classes (Figures 3). In these maps of soil attributes, regions were identified with high and low values resulting from spatial dependence.

According to Vieira and Dechen (2010), when there is spatial dependence, estimating value for unsampled areas by means of kriging occurs optimally that is, with no trend and minimum variance.

Some correlations between the soil attributes featuring the same soil uses, that is, at the same sampled area, become clear in the maps. At the degraded substrate, higher values of MWD and percentage of aggregates (using the rainfall simulator) at the lower portion of the plot were observed. At the recovered soil, macroporosity, total porosity and soil density (Figures 3. f; i and k) showed high correlation, that is, places with higher macroporosity and total porosity showed the lowest values of soil density. However, the MWD at the recovered soil did not correlate with these attributes, which may be justified by the different methods used for obtaining MWD in comparison to those used to obtain the other attributes.

At the soil covered by pasture similarities between total porosity and MWD were observed (Figures 3. j and d). The upper portion of the plot showed the highest values for these attributes. Regarding the microporosity, although spatial dependence structure was detected, the attribute's behavior was not similar to that of the other attributes under the same land uses. The areas presenting spatial dependence structure in the map show differences in soil physical attributes, which may cause differences in plant development, especially under the uses characterizing correlation between soil attributes: at the degraded substrate, at the recovered substrate, and under pasture.

These results indicate spatial dependence especially in areas which have undergone some kind of impact.


a)
b)
c)
d)
e)
f)
x
Y
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
6.2
5.7
5.2
4.7
4.2
3.7
3.2
2.7
2.2
2.3
2.1
1.9
1.7
1.5
60
50
40
30
20
10
0.21
0.19
0.17
0.15
0.13

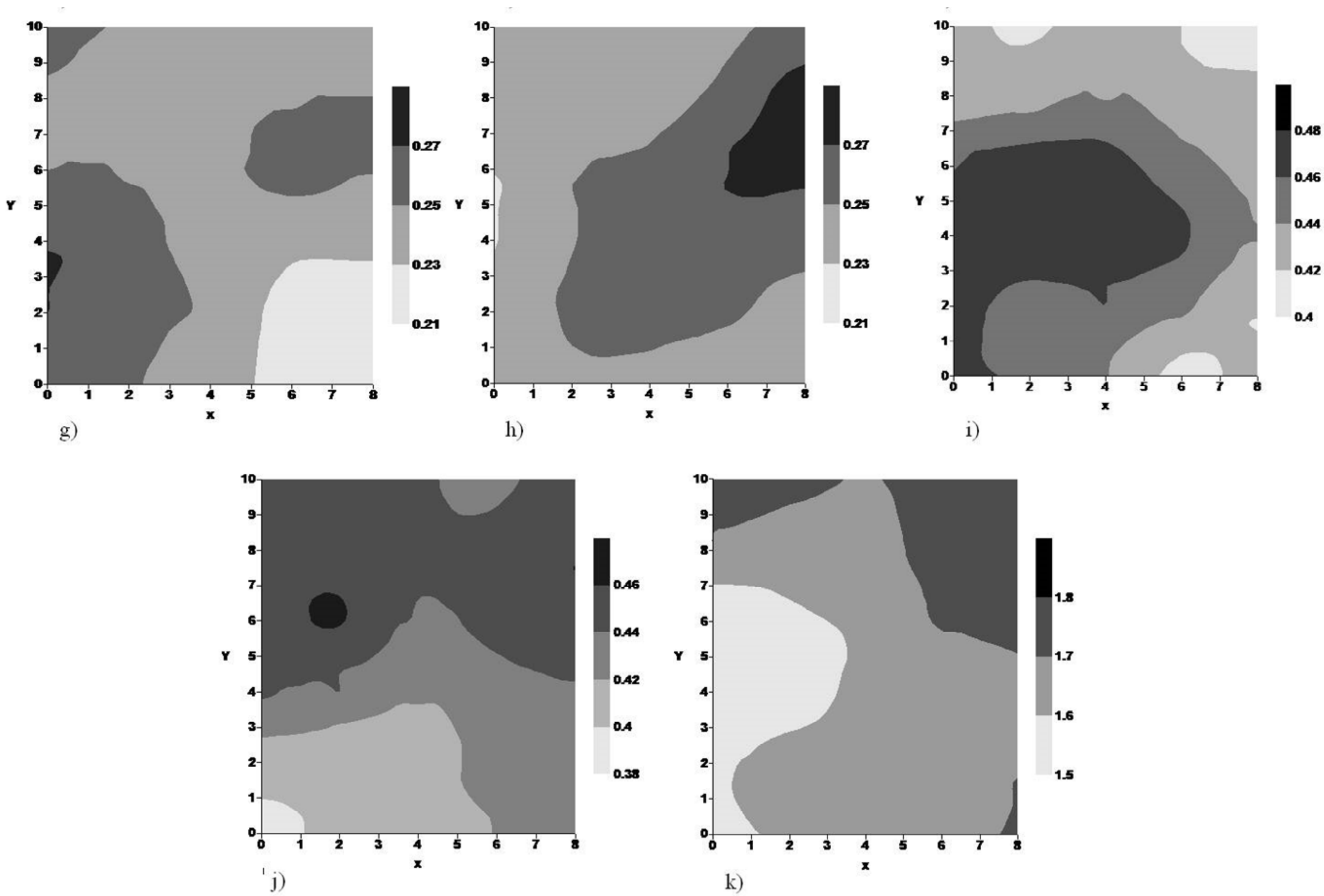


Figure 3. Isoline maps obtained from data spatialization using ordinary kriging of the soil's physical attributes: a) MWD – SD; b) MWD – SR; c) MWD – SC; d) MWD – SP; e) aggregates under simulated rainfall at the 9.52–4.00-mm class; f) macroporosity – SR; g) microporosity – SDLE; h) microporosity – SP; i) total porosity – SR; j) total porosity – SP; and k) density – SR.

Therefore, care should be taken when considering these areas homogeneous in further studies.

Conclusions

The removal of the part of soil profile created an environment where spatial variability depends on the distance that separates the samples. The intrinsic differences to the most surface and subsurface soil horizons enabled the spatial dependence of the structure, porosity and density under the degraded and regenerated land uses, probably due to the removal of soil at different depths for the construction of the hydroelectric power station.

Areas delimited using spatially dependent data were identified in the maps of soil attributes, which indicates differences in their physical potential for plant development. Therefore it is not correct to consider these areas as homogeneous for future experimental agricultural activities. It can be stated that two methods used to evaluate the state of aggregation of the different managements are not equivalent. But both contribute to verify the state of aggregation under the differentiated action of water.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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