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Comparison of South African occupational exposure limits for hazardous chemical substances with those of other countries

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Preface

The mini-dissertation was written in article format with accordance to the General Academic Rules (Rule A.13.7.3) of the North-West University. The Annals of Occupational Hygiene was chosen as the journal for potential publications for this study. Details regarding the specifications and referencing for the journal is specified and can be found at the beginning of Chapter 3 in the author's instructions. The reference style of Annals of Occupational Hygiene is used within the whole mini-dissertation for the sake of uniformity. The lists of references are given at the end of each chapter in alphabetical order, using the Vancouver style of punctuation and abbreviation as required by the journal. The preferred language of this mini-dissertation is English and the document has been proof-read and edited by a competent person (see Chapter 6).

Author's Contribution

A number of researchers were involved in the planning and completion of this study. The individual contributions of each of the researchers involved are listed below:

NAMES	CONTRIBUTIONS
Ms L Viljoen	- Planning and protocol development of study - Collecting and sorting of data - Literature study and statistical analysis - Interpretation of results - Writing of the mini-dissertation
Prof JL Du Plessis	- Supervisor - Assisted in the planning and execution of the study - Professional guidance and input in the study - Assisted in the analysis and interpretation of results - Reviewing the mini-dissertation and relevant documentation
Ms A Franken	- Co-supervisor - Assisted with planning and coordination of the study - Professional input and providing recommendations - Reviewing the mini-dissertation and relevant documentation

The following is a statement confirming the contributions of each of the relevant individuals involved in the study:

I declare that I have approved the article and that my role in the study as indicated above is representative of my actual contribution and that I hereby give my consent that it may be published as part of Liandi Viljoen's MSc (Occupational Hygiene) mini-dissertation.

Prof JL Du Plessis	Ms A Franken
(Supervisor)	(Co-supervisor)

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No one who achieves success does so without the help of others.

The wise and confident acknowledge this help with gratitude.

- Alfred North Whitehead-

Summary

Various hazardous chemical substances are used daily as part of manufacturing and processing. Exposure to these hazardous chemical substances (HCSs) can cause adverse health effects in the exposed workers. Occupational exposure limits (OELs) are used to control exposure to these HCSs and thereby protect workers from the adverse effects that exposure may induce.

The aim of this study was to compare South African list of OELs as contained in the Hazardous Chemical Substance Regulations (HCSR) to several developed and developing countries based on two aspects: (1) the number of substances that are selected and regulated by the lists of each country (2) and the overall level of the OELs set by the different countries and jurisdictions. Due to the nature and the large amount of data the study is divided into two parts. The first part is a comparison of South African OELs with nine developed countries and jurisdictions along with the Mine Health and Safety Act Regulation 22.9 (MHSR) of South Africa. The second comparison was conducted between South African and the four developing BRICS countries. BRICS is an acronym for: Brazil, Russia, India, China and South Africa, all are leading developing countries. Substance selection and coverage was compared by analysing the number of overlapping and uniquely regulated OELs that existed between countries. The over-all level of OELs was determined and quantified by using the statistical method, the geometric means of ratios. These ratios were compared in order to establish how the levels of OELs of the South African HCSR compare with the level of the various other countries.

Results indicated that there are large and unsystematic differences between the selection of HCSs that are regulated by different countries and jurisdictions. Individual coverage and selection of HCSs between the various developing and developed countries and jurisdictions in the study was inconsistent and dissimilar. A high number of HCSs are regulated by only one of the various countries included in this study. Among the developed countries 20.8% of substances are uniquely regulated, whereas 46% of HCSs are regulated by only one of the various developing countries. According to the geometric means of ratios Occupational Safety and Health Administration (OSHA) is the only jurisdiction in a developed country that has a higher overall level of OELs when compared to South Africa as for the rest of the developed countries they all yielded a lower overall level of OELs. American Conference of Governmental Industrial Hygiene (ACGIH) had the lowest overall level of OELs.

When compared with the BRICS countries South Africa had a higher overall level of OELs. The average overall level of OELs differs substantially between the BRICS countries; Russia having the lowest, and Brazil having the highest overall limit when compared relative to South African HCSR. Strong similarities were found between South African HCSR and MHSR indicating national similarity. The South African OELs for HCSs have an overall higher level than the majority of developed and developing countries. Various factors may be responsible for these differences among countries and jurisdictions. These factors include, variations in scientific reasoning, the risk acceptance of the negative impact that various HCSs might induce and the time lags that countries have between updates. Further differences may be explained by the difference in consideration of socio-economical and practical feasibility of an OEL and the predominant industries in a country.

***Key words**: occupational exposure limits, comparison, developed countries, jurisdictions, developing countries, BRICS, hazardous chemical substances*

Opsomming

ŉ Verskeidenheid gevaarlike chemiese substanse word daagliks gebruik as deel van vervaardiging en prosessering. Blootstelling aan die gevaarlike chemiese substanse (GCSe) kan nadelige effekte op die gesondheid van die blootgestelde werker hê. Beroepsblootstellingsdrempels (BBD) word gebruik om blootstelling aan die GCSe te beheer en sodoende die werkers te beskerm teen die nadelige effekte van blootstelling.

Die doel van die studie was om Suid Afrika, as ontwikkelende land, se BBDs soos vervat in die Gevaarlike Chemiese Substans Regulasies (GCSR) te vergelyk met ŉ verskeidenheid ontwikkelde en ontwikkelende lande gebaseer op twee aspekte: (1) die hoeveelheid en seleksie van substanse wat deur elke land gelys word en (2) die algehele vlak van die BBDs wat deur elke land of jurisdiksie gestel word. As gevolg van die aard en die hoeveelheid data ingesamel in die studie is die studie in twee dele verdeel. Die eerste is ŉ vergelyking van Suid Afrika se BBDs met nege ontwikkelde lande en jurisdiksies saam met Die Myn Gesondheid en Veiligheids Wet Regulasie 22.9 (MGVR) van Suid Afrika. Die tweede vergelyking is tussen Suid Afrika en vier ontwikkelende lande naamlik die BRICS lande. BRICS is ŉ akroniem vir: Brasilië, Rusland, Indië, Sjina en Suid Afrika, hul is almal vooraanstaande ontwikkelende lande. Die seleksie van substanse was vergelyk deur die aantal substanse wat ooreenstem sowel as die aantal substanse uniek deur elke land gereguleer, te ondersoek. Die algehele vlak van die BBDs van elke land is vergelyk deur gebruik te maak van ŉ statistiese metode naamlik die verhoudings van geometriese gemiddeldes. Die verhoudings is vergelyk om vas te stel hoe Suid Afrikaanse GCSR vergelyk met die verskeie ander lande.

Resultate toon aan dat daar omvangryke en onsistematiese verskille is in die seleksie en regulering van substanse tussen verskillende lande en jurisdiksies. Individuele seleksie van GCSe tussen verskeie ontwikkelde en ontwikkelende lande en jurisdiksies in die studie was oneweredig en het verskil tussen lande. Die grootste aantal substanse word slegs deur een van die verskeie lande in die studie gereguleer. Tussen die ontwikkelde lande word 20.8% van die totale aantal substanse net deur een land gereguleer en 46% van die totale aantal substanse word deur slegs een van die ontwikkelende lande gereguleer.

Volgens die verhoudings van geometriese gemiddeldes is Occupational Safety and Health Adminastrative (OSHA) die enigste jurisdiksie in ŉ ontwikkelde land wat hoër algehele vlakke van BBDs het as Suid Afrika, al die ander ontwikkelde lande het algeheel laer waardes. American Conference of Governmental Industrial Hygiene (ACGIH) het die laagste algehele vlakke van BBDs gehad. Wanneer Suid Afrika vergelyk word met die BRICS lande het Suid Afrika hier ook algeheel hoër vlakke van BBDs. Die gemiddelde algehele vlak van BBDs verskil betekenisvol tussen die verskeie BRICS lande; Rusland het die laagste vlak en Brasilië het die hoogste algehele vlak relatief tot die Suid Afrikaanse GCSR. Sterk ooreenstemmings is gevind tussen Suid Afrikaanse GCSR en MGVR wat ŉ aanduiding is van nasionale ooreenkomste. Die Suid Afrikaanse BBD vir GCSs het ŉ algehele hoër vlak as die meerderheid ander ontwikkelde en ontwikkelende lande. ŉ Verskeidenheid faktore kan verantwoordelik wees vir die verskille wat daar bestaan tussen die lande. Die faktore sluit in, verskille in wetenskaplike beredenering, die risiko aanvaarding van die nadelige effekte van verskeie GCSe mag veroorsaak en die tyd verloop tussen opdaterings. Verdere verskille kan verduidelik word deur die verskille in oorweging van sosio-ekonomiese en praktiese toepasbaarheid van ŉ BBD en die oorheersende industrieë in ŉ land.

***Sleutelterme**: beroepsblootstellingsdrempels, vergelyking, ontwikkelde lande, ontwikkelende lande, BRICS, gevaarlike chemiese substanse, jurisdiksies*

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List of abbreviations and symbols

% -	Percentage
ACGIH -	American Conference of Governmental Industrial Hygienists, United States of America
ACTS -	Advisory Committee on Toxic Substances, United Kingdom
AGS -	Ausschuss für Gefahrstoffe, Germany
BC -	British Columbia, Canada
℃ -	Degrees Celsuis
CAS -	Chemical Abstracts Service
CL -	Ceiling Limit
CO -	Carbon Monoxide
COSHH -	Control of Substances Hazardous to Health Regulations, United Kingdom
DFG -	Deutsche Forschungsgemeinschaft, Germany
HCS -	Hazardous Chemical Substance
HCSR -	Hazardous Chemical Substances Regulations
HDI -	Human Development Index
HSC -	Health and Safety Commission, United Kingdom
HSE -	Health and Safety Executive, United Kingdom
HTP -	Haitalliseksi tunnetut pitoisuuder (HTP-values), Finland
IARC -	International Agency of Research on Cancer
JSOH -	Japan Society of Occupational Health
LD_{50} -	Lethal Dose

LOAEL - Lowest Observed Adverse Effects Level

MAC - Maximum Allowable Concentration

MHLW - Ministry of Health Safety and Labour, Japan

MHSA - Mine Health and Safety Act, South Africa

MHSR - Mine Health and Safety Regulations, South Africa

mg/m^3 - milligrams per cubic meter

MOHAC - Mining Occupational Health Committee

mppcf - million particles per cubic foot of air

NGV - Nivågränsvärde, Sweden

NIOSH - National Institute for Occupational Safety and Health, United States of America

NOAEL - No Observable Adverse Effect Level

OELs - Occupational Exposure Limits, generally the term refers to an 8-hour time-weighted average referred to by the different countries. Also used as a term to generically refer to a collection of TWA, STELs and CLs

OEL-CL - Occupational Exposure Limit, Control Limit

OEL-RL - Occupational Exposure Limit, Recommended Limit

OSH - Occupational Health and Safety

OHS-Act - Occupational Health and Safety Act, South Africa

OSHA - Occupational Health and Safety Administration, United States of America

PEL - Permissible Exposure Limit

ppm - parts per million

REACH - Registration, Evaluation, Authorization and Restriction of Chemicals, European Union

Sen - Sensitisation notation

Sk - Skin notation

STEL - Short Term Exposure Limit

SWEA - The Swedish Work Environment Authority, Sweden

TLV - Threshold Limit Value

TRGS - Technical Guidance Concentrations

TRK - Technishe Richtkonzentrationen (Technically-feasible Guidance Concentrations), Germany

TWA - Time Weighted Average refers to exposure over an 8-hour period as reference

UK - United Kingdom

USA - United States of America

USSR - Union of Soviet Socialist Republic

WHS - Work Health and Safety Act, Australia

Chapter 1: General introduction

1.1 Introduction

The use of chemical substances in industries is inevitable; as it forms part of countless processes in the manufacturing and producing of goods and services. Chemical substance exposure however, is often associated with adverse health effects in workers (Rappaport and Kupper, 2008; Ding *et al*., 2011; Schenk and Johanson, 2011). This has become a major concern in occupational and industrial hygiene professions (Hämäläinen *et al*., 2009; Schenk and Johanson, 2011).

Occupational exposure limits (OELs) are some of the most effective aids for controlling exposure and protecting the workers' health (Adkins *et al*., 2009). These limits are implemented in order to regulate exposure to hazardous chemical substances (HCS) at a maximum allowable concentration that may be present in a work environment. An OEL is therefore defined as the concentration of a workplace hazard that most workers may be exposed to without harming their health or posing risks for adverse health effects. OELs have been used since the early 1900's, and developed over the years in such a way that most countries have national authorities that are responsible for setting and implementing OELs (Rappaport and Kupper, 2008).

Even though OELs are set to be some of the most effective aids for controlling exposure to HCSs, the processes used for setting these OELs are complex and diverse so that in many cases the main focus, to protect a workers health, may be lost (Adkins *et al*., 2009). A final concentration of an OEL set does not only rely on the consideration of health effects but also on other socio-economical and technical aspects defining the OELs feasibility (Ding *et al*., 2011). It is these aspects that have a major influence on how OELs are set by different countries and gives rise to considerably different outcomes and processes. The inconsistencies that exist are based on the disparity of these two aspects namely; the determination of how safe an OEL is, called the health based or scientific aspect, and the second referring to how affordable and practical it is to implement an OEL, the socio-economical and practical aspect (Liang *et al.,* 2006).

Variations among these two aspects set the foundation for several other questions relating to the effectiveness and adequacy of OELs to protect against the adverse health effects caused by exposure to a variety of HCSs. There are a number of different factors proposed that attempt to explain why these variations in the OELs of different countries do exist (Hansson and Ruden, 2006; Ding *et al*., 2011; Schenk *et al*., 2008). The extent to which an OEL can in fact protect a worker's health can be quantified by assessing the different OELs available and comparing the best foundation and value of OELs set by different countries and jurisdictions.

According to Hansson and Ruden (2006) studies done on the comparison of OELs specifies that there are unsystematic differences in the processes and implementation of OELs. This is further emphasized by the fact that even HCSs that have similar health effects are not approached and treated in the same way when it comes to setting an OEL (Hansson and Ruden, 2006). There is great need for harmonization and standardisation of OEL setting processes across the globe (Liang *et al*., 2006; Schenk and Johanson, 2011). This is needed in order to eliminate or at least improve the inconsistency among different countries. Harmonization however, is not always made out to be the best way of improving OELs by all in the field (Vincent, 1998).

South Africa is a developing country and it is of importance to determine the adequacy of OELs as they are used by occupational hygiene practitioners on a daily basis to protect the health of the South African workforce. South African OELs for general industries, as contained in the Hazardous Chemical Substances Regulations (HCSR), were implemented in 1995 and only a few amendments have been made since then (South African Department of Labour, 1995). A further list of OELs is used for the mining industries in South Africa. These are contained in the Regulation 22.9 of the Mine Health and Safety Act of 1996 and were last updated in 2006 (South African Department of Minerals and Resources, 2006). Henceforth these regulations will be referred to as the Mine Health and Safety Regulations. Comparison is made to identify and describe differences between OELs of the South African HCSR and MHSR, developed countries as well as other developing (BRICS) countries. BRICS is an acronym that refers to the economies of: Brazil, Russia, India, China and South Africa. The BRICS countries are of importance as they stand prominently as leading developing countries (Ministry of Finance, Government of

India 2012). The comparison will be done with respect to two main variables: coverage of individual HCSs referring to the number of HCSs listed by each country and the overall level (concentration) of OELs set for the different HCSs.

In conclusion, evaluating and comparing the different lists of OELs can help determine the adequacy of South African OELs and whether there is a significant difference in the limits set between different countries and jurisdictions.

1.2 Research aims and objectives

The aim of this study is to:

- Comparatively analyse the OELs in the South African HCSR with that of MHSR, developed countries and other developing (BRICS) countries to establish how South African OELs differs from other countries.

The specific objectives of this study are to:

- Compare South African OELs in the HCSR to the MHSR and various other countries and jurisdictions, in developed and developing countries according to two main variables:
    - Selection and coverage of individual HCSs.
    - The overall level of exposure limits set for the different HCSs.

1.3 Hypotheses

Hypothesis 1: There are considerable differences in the number of HCSs that are listed in the South African HCSR in comparison with those of other countries.

Hypothesis 2: The level at which South African OELs in the HCSR are set differs significantly from those set by developed and other developing countries.

1.4 References

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Chapter 2: Literature study

In this chapter the history, development and implementation of OELs will be discussed. Different countries and jurisdictions relating to this study, that set OELs will also be critically discussed.

2.1 Rationale behind occupational exposure limits

Industries rely on the use of chemical substances to facilitate or create the products or services that are produced. The larger the industry and demand is the more it increases the variety of chemicals used. Exposure of workers to these chemicals can often cause negative health effects. The incidence of occupational accidents and work-related disease has grown to be of major concern at both country and company level (Hämäläinen *et al*., 2009; Schenk and Johanson, 2010).A global trend of occupational accidents and fatal work-related disease is presented by Hämäläinen *et al*, (2009). They reported 29 798 fatal work-related disease' in South Africa in the year 2002 and close to two million worldwide. These numbers however does not only include the disease caused by hazardous airborne chemical substances but also deaths due to other factors such as occupational accidents (Hämäläinen*et al*., 2009). Many occupational diseases responsible for the statistics provided are caused by past exposure, for example the development of mesothelioma 20 to 40 years after exposure to asbestos.

The development of occupational disease can be controlled by regulatory action taken by authorities in order to protect the workers in the industries from exposure to the specific HCS and henceforth against negative health effects. Different ways to control exposure exists and it varies from prohibited to restricted exposure. Most often the exposure is restricted through regulation of the maximum acceptable concentration of a HCS in the workplace air that are referred to as OELs. This study focuses on the exposure limits for HCSsand excludes the limits set for other physical stressors such as noise, heat-stress, cold-stress and vibration (Klonne, 2003; Paustenbach *et al*.,2011).

2.2 What are occupational exposure limits?

OELs are limits set by different jurisdictions and industrialised countries' and are enforced as part of a country's legislation to help protect the workers from the negative health effects of chemical exposure. An OEL is the concentration of a workplace hazard (in the air) that most workers can be exposed to without harming their health or posing risks for adverse effects (Rappaport and Kupper, 2008). These limits should therefore aim to be as close to zeroas possible. This is however rarely the case and therefore authorities sets OELs as guidelines to aidhealth and safety practitioners in protecting workers health. The efficiency of an OELto protect against a variety of adverse health effects relies on the successful understanding of the suspected risk and the harmful potential a specific HCS possesses (Perkins, 2008). The use of an OEL as part of risk assessment and control of exposure to HCSsis a well-known method and is implemented or adopted by industries all over the world. In using an OEL to evaluate exposure of a worker to a HCS it is important to note that OELs do not distinguish between safe and unsafe levels of exposure (Schenk and Johanson, 2011). Thus OELs cannot be seen a definite safe level of exposure for all workers. They do still need to be implemented to protect a country's workforce and also to protect the industries from liability(Rappaport and Kupper, 2008).

2.3 History and development of OELs

OELs have been in use since the early 1900's and in the past 60 years they have developed so rapidly that most industrialised countries have a national authority or organisation issuing their own lists of OELs (Paustenbach *et al*.,2011; Schenk *et al.*, 2011). Since long before the 1900's it was well known that the exposure to airborne HCSscould exert negative effects on people who areexposed, but the lack of sampling and analytical equipment made progression of the process difficult. Dr. Alice Hamilton,one of the first pioneers in Occupational Medicine, felt that no methods were necessary and that a correlation between exposure to HCSsand illness or death could be drawn by simple observations. One of the earliest efforts to determine safe levels for HCSs,dates back to experiments done by Max Gruber which was published in 1883. His publication dealt with the effects of carbon monoxide (CO) on experimental animals (hens and rabbits) to get a sense of what a safe limit of exposure to CO would be(DiNardi, 2003; Paustenbach *et al*., 2011).

In the following years extensive animal experimental data of the exposure to a variety of different HCSswas gathered and compared.In 1912 the first list of acute exposure limits was published by Kobert and consisted of a table with 20 HCSs and was called“The Smallest Amount of Noxious Industrial Gases which are Toxic and the Amounts Which Might be Endured” (DiNardi, 2003).Many of the HCSssuch as hydrochloric acid and ammonia listed in the table under “only minimal symptoms” agrees with values that are usually accepted in present-day maximum allowable concentration (MAC) tables (Brandys and Brandys, 2008), although the values of the more toxic organic substances far exceeded those currently in use. Prior to the 1920’s some of the first OELs related to dust exposure where based on exposure of workers in South African gold mines where large amounts of dust containing crystalline silicawas generated. South Africa set an exposure limit for dust with 80%-90% quartz content at 8.5 million particles per cubic foot of air (mppcf) in the year 1916. In the subsequent years after the 1920’s more comprehensive lists of OELs were published, such as a list of exposure limits for 33 HCSsby the United States Bureau of Mines, International Critical Tables exposure limits for 27 substances and a list published by the Union of Soviet Socialist Republic (USSR) Ministry of Labour in 1930 containing 12 industrial HCSs(Paustenbach*et al*., 2011).

Despite the rapid development of OELs, the number of published OELs were limited and not widely accessible (Perkins, 2008). The first list of standard limitsof exposure to HCSsin the industry was called MAC values. Thereafter the American Conference of Governmental Industrial Hygienists (ACGIH) published the first list of Threshold Limit Values (TLV) in 1956. Many developed and developing countries did not have their own list of OELs and therefore adopted the TLVs of the ACGIH as a starting point earlier on. History is still repeating itself as many countries are still adopting and implementing these values (Brandys and Brandys, 2008). The process by which ACGIH has come to set their OELs has been the object of criticism many times before.

This was due to insufficient scientific basis on which they were said to be based on (Castleman and Ziem, 1989; Hansson and Ruden, 2006; Rappaport and Kupper, 2008; Ding *et al*., 2011). The criticism was further based on the fact that, a strong correlation was found between TLVs and the measured exposure in the industry rather than with the association with negative health effects (Schenk *et al.*, 2008a). History has proven that the development of OELs and the management of safe levels of exposure at a workplace are necessary to aid in protecting a workforce against the negative effects of exposure to HCSs.

2.4Types of OELs

For exposure to airborne HCSsthree types of OELs are commonly used: time-weighted average exposure limits (TWA), short term exposure limits (STEL) and ceiling limits (CL). Firstly, the TWAexposure limitsare the maximum allowable concentrations of substances in the air for an 8 hour working day and a 40 hour working week (Paustenbach*et al*., 2011). A STEL on the other hand,is the maximum concentration of an airborne contaminant for a short time interval which is usually 15 minutes (South African Department of Labour, 1995). The last type of OEL, the CL isa concentration concerning an even shorter time of exposure often five minutes (Schenk and Johanson, 2011). The most common type of OEL used to express the control needed for exposure in the workplace is the OEL-TWA (Schenk and Johanson, 2010). Nevertheless all of these OELs together are the cornerstones of occupational hygiene in most industrialised countries. Countries and jurisdictions refer to their OELs differently and the different designations used are discussed later under each of the individual countries and jurisdictions used in the study.

2.5 Aspects leading to varying OELs

Setting an OEL is part of a process called the risk decision and this process differs between different countries as well as between the regulatory areas within a country (Schenk and Johanson, 2010). Different standard-setters therefore have different procedures that they follow in order to set an OEL for a specific HCS. But the process used can also be somewhat similar. Schenk and Johanson (2011) depicts in Figure 1 a probable process that is followed for setting OELs. The methodused to determine these exposure limits,as well as which health effects they are meant to protect the worker from, differs from one authority to the next.

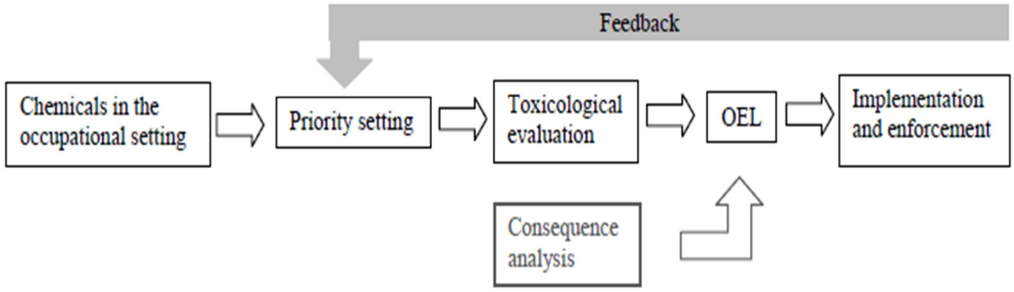

Figure 1: Process concerning the setting andimplementation of OELs (Schenk and Johanson, 2011)

Despite significant dissimilarities, all standard-setting authorities have a mutual understanding that for a substance to be regulated by an OEL the specific HCS in question must first be proven to be harmful to human health. Only thencan it be determined at which limits these substances need to be controlled in order to protect the worker's health(Hansson and Ruden, 2006). The final concentration of the set OELs however, does not only rely on this consideration of health effects but also on other socio-economical and technical aspects defining the OEL's feasibility as well as the time lags between updates of lists.

It is these aspects that have a major influence on how OELs are set by the different countries and gives rise to considerably different outcomes and processes of setting and implementing an OEL concentration (Ding *et al.*, 2011; Schenk and Johanson, 2011). Both these aspects regarding the setting of OELs and the influence they have are discussed in the following sections.

2.5.1 Health-based perspective of setting OELs

Due to the fact that an OEL is meant to protect against adverse health effects, as well as indicatinganacceptable level of risk, the emphasis falls strongly on the health-based perspective. Health-based perspective refers to the use of different toxicological models and dose-response evaluations to determine an OEL from the most recent available scientific and human experience/exposure data. Selection and evaluation of available scientific data is a possible source of the major differences in the OELs (Schenk and Johanson, 2010). In this context it is important to note that OELs do not protect all workers all of the time but applies to a workforce that, on average, is more healthy than the normal population. Factors such as physiological state, genetics, biological diversity and other elements relating to individual differences are not taken into consideration when authorities set an OEL (Klonne, 2003; Perkins, 2008).

The primary route of exposure is generally through inhalation, however the effects are systemic, and therefore a variety of different methods and models exist to quantify the risks for adverse health effects that a HCS possess. It is also important to note that inhalation is the primary, but not the only, route of exposure and therefore skin notations (Sk notations) exist. A skin notation indicates that absorption through the skin can make a significant contribution to the overall exposure of a worker (South African Department of Labour, 1995). Toxicological principles and available data can aid in the process of setting a health based OEL by considering the following aspects (Paustenbach*et al*., 2011).

2.5.1.1 Chemical properties

Data obtained from a general review of the physical and chemical aspects of the HCS that is in question can already aid in understanding of what the health effects of human exposure might be. The inherent properties such as physical state, stability, solubility, and route of exposure among other factors can provide important information. An example is that vapour pressure data can provide information on the tendency of the chemical to volatilize and create harmful concentrations of the substance in the air (Klonne, 2003).

2.5.1.2 Acute and chronic toxicity

Evaluation and consideration of acute versus chronic toxicity is a very important part of the toxic evaluation as part of the OEL setting process (DiNardi, 2003; Schenk and Johanson, 2011). A relatively rudimentary estimate of toxicity is obtained from acute toxicity data (Klonne, 2003). Data is usually obtained through experimental testing on animals based on exposure to a single dose and the observed effect over a period of 14 days and many times it is expressed as an approximate lethal dose (e.g., LD_{50})(Eaton and Gilbert, 2008). Acute toxicity has death as the foremost endpoint. A HCS that has a high occurrence of effects after exposure to a substance, for a short period of time, possesses a risk associated with acute toxicity and such a HCS will most likely have a lower OEL than otherHCSs. This data also assists in determining whether a HCS should be assigned a STEL or even a CL(Klonne, 2003).

Chronic toxicity, on the other hand, is when negative health effects are only manifested after a prolonged period of exposure. Animal studies are also used in this case but exposure is done over a period of time and used to determine the effects of the HCS due to repeated exposure.These tests are primarily used to establish a no observable adverse effect level (NOAEL) for a HCS or a lowest observed adverse effects level (LOAEL) (Eaton and Gilbert, 2008). Both of these are used in the establishmentof OEL concentrations for HCSs(Paustenbach*et al*., 2011).

2.5.1.3 Irritants and sensitization

Ammonia, hydrogen sulfide, and formaldehyde are some of the HCSs that are classified as sensory irritants that may cause undesiredhuman health effects. These irritants have a vast spectrum of effects such as pulmonary irritation or irritation of the eyes and skin. CL and STEL are usually assigned to acting irritants by the ACGIH in its lists of TLVs (Paustenbach*et al.,* 2011). Some health professionals believe that irritation does not constitute material impairment of health while others believe that it should have OELs and workers should be protected against the effects of irritants (Meldrum, 2001; Paustenbach*et al*., 2011).

HCSs that produce a sensitization reaction are usually notated with a sensitization notation (Sen) in tables of OELs to indicate that the worker exposed may become sensitised toward the specific HCS. Sensitization is an immune reaction where the initial exposure to a chemical produces no response. After several exposures if sensitization has alreadyoccurred the HCS can produce severe adverse health effects even at subsequent lower dosages than previously exposed to. An example of such a reaction is anaphylaxis, a severe allergic reaction of the whole body caused by a HCS that has become an allergen due to sensitization. Symtoms such as red raised itchy skin rash, narrowing of your airways and a sudden drop in blood pressure is typical of an anaphylactic reaction (Eaton and Gilbert, 2008). This makes the worker more susceptible for negative health effects due to the exposure of a HCS, and is therefore more sensitive than the general population for which OELs are set (Du Plessis*et al*., 2010).

2.5.1.4 Neurotoxicity, reproductive toxicity, genotoxicity and carcinogens

Some HCSsproduce an effect directly at the site of exposure and others are absorbed by the body and have systemic effects in other parts of the body. For this reason a chemical needs to be classified with regard to the type of toxic reaction it causes. These effects can range from general toxicity to genotoxicity. Generally when setting an OEL the chemical substance in question is evaluated based on its ability to produce toxic effects on the reproductive and developmental system, nervous system and the risk of genetic damage. Thus the data usually involved in the evaluation includes: reproductive/developmental toxicity data, neurotoxicity data and genotoxicity. As the industries across the world have grown, it has become apparent that the effects that chemical exposure has on the reproductive system and on the developing fetus, is one of the primary concerns (DiNardi, 2003; Nielsen and Steinar, 2008). Neurotoxicity refers to the effects that a chemical can induce on the nervous system. Many substances have the ability to produce negative effects on the nervous system. The use of neurotoxicity data however attempts to distinguish between chemicals with readily reversible effects and those with more serious effects that are not easily reversed (DiNardi, 2003; Shuker*et al.*, 2007).

Gene mutations and other effects of genotoxic substances are most often closely associated with the carcinogenic classification of a substance. Setting OELs for HCSs that have the potential to produce genetic mutations and chromosomal aberrations are supported by extensive animal studies. Chemical carcinogens have been a major focus area for occupational and environmental regulating agencies for the past 25 years (Paustenbach*et al*., 2011). The most common classification used to classify the carcinogenic effects of a potentially hazardous substance is by placing it in one of the following categories as used by the TLV committee: A1-Confirmed human carcinogen, A2- Suspected human carcinogen, A3- Confirmed animal carcinogen with unknown relevance to humans, A4- Not classifiable as a human carcinogen and A5- Not suspected as a human carcinogen. Another popular and widely used classification of carcinogens is the International Agency of Research on Cancer (IARC) classification: Group 1 Carcinogenic to humans, Group 2A Probably carcinogenic to humans, Group 2B Possibly carcinogenic to humans, Group 3 Not classifiable as to its carcinogenicity to humans, Group 4 Probably not carcinogenic to humans. Exposure to HCSs classified as carcinogens must be avoided or levels must be kept as low as possible (DiNardi, 2003, Paustenbach*et al*., 2011). Most countries and jurisdictions mention that HCS is classified as carcinogens and also to which classification it belongs.

2.5.1.5 Human experience and epidemiological data

The number of well controlled and significant epidemiological occupational exposure studies is small (DiNardi, 2003).Epidemiological evidence of harmful effects of HCSs originates from scientific research done on occupational exposure and observational effects of such exposure (Schenk and Johanson, 2011). Data obtained from human exposure is considered to be the most valuable in setting an OEL.

The health effects of a HCS are observed directly in the exposed person or worker and there is no need for extrapolation from animal data to determine the effects. However setting an OEL at a specific concentration based on epidemiological data, can only be done if the reliability and accuracy of the data is verified. It is clear from the literature that there are many discrepancies when it comes to the setting of a health-based OEL and the methods and data used varies from one authority to the next (Hansson and Ruden, 2006; Schenk and Johanson, 2010;Schenk and Johanson, 2011). Each of the standard-setting authorities has documentation that assist in understanding how they have come to set an OEL at an exact value but these documentations are not always accessible. This documentation also state which types of data has been used whether it is animal, human or epidemiological studies. As previously stated the health-based aspect is not the only aspects taken into consideration when setting an OEL. Not only human health but also technical and practical feasibility are taken into account when determining a concentration for an OEL (Liang *et al*., 2006; Ding *et al.*, 2011; Schenk and Johanson, 2011).

2.5.2 Socio-economic and technical feasibility of OELs

The decision making process and establishment of an OEL does not exist in a scientific vacuum. Countries have committees that form part of the decision making process. These committees' take aspects such as socio-economic and technical viability into consideration(Klonne, 2003). To what extent it is practicable and affordable to set and maintain a HCS at the specified OEL, is an additional factor for the diversity and variation of the OEL values. Each country or jurisdiction has its own criteria of which factors are considered in order to set a practicable standard that relates both to the authorities in question and the corporate as well as industrial bodies involved. Discrepancies in the decision making process of the different countries can be based on a variety of policies, politics and corporate influences. All of which influence the regulatory machinery of an OEL setting authority in their own way (Klonne, 2003). These non-scientific aspects play a key role in the overall understanding of OELs and needs to be taken into consideration when comparing OELs of different countries and jurisdictions (Schenk and Johanson, 2010).

Paustenbach *et al*. (2011) states that nearly all countries and jurisdictions, that set OELs, claims the legal complications as the most difficult and controversial part of the entire OEL setting process. Several attempts have been made to separate the scientific and toxicological aspects from the other policies and issues surrounding this process (Hansson, 1997). As stated earlier the ACGIH's TLVs have been the object of scrutiny many times before where it has been claimed that the technical and socio-economic feasibility has become too influential (Hansson and Ruden, 2006; Schenk *et al*., 2008a).Nevertheless the consideration of technical and socio-economic feasibility remains part of the decision making process as the analysis of the consequences of setting and implementing OELs at specific concentrations. Consequence analysis of the data as shown in Figure 1 may influence the level at which an OEL is set (Schenk and Johanson, 2011).

2.5.3 Time-lags between updates

The time lags between updates for the lists of OELs has previously been identified as one of the most influential reasons for the lack of standardized OELs within various jurisdictions and emphasizes the need to amend and update OELs regularly (Schenk and Johanson, 2010). It has been shown that OELs appear to have decreased gradually over time if they are revised. Revision forms an important part of the process of setting an implementing OEL values (Hansson, 1997; Schenk and Johanson, 2011).

2.6Harmonization of OELs

The actual OELs set by different countries still differ significantly (Liang *et al*., 2006),despite the many attempts that have been made previously. These attempts include REACH, the European Community Regulation on chemicals and their safe use. REACH (EC 1907/2006) is one of the more current attempts for harmonization in the European Union (EU) and is an acronym for the Registration, Evaluation, Authorization and Restriction of Chemical substances. With the rapid development of economic globalization there is a need for international harmonization for substance selection and setting of OELs (Liang *et al*., 2006; Schenk and Johanson, 2011).

Hansson and Ruden(2006) states that studies of OELs indicate large and unsystematic differences between decisions made and values set for HCSs with similar types of adverse health effects. Many benefits can come from harmonization of the methods and approaches used in setting OELs (Schenk *et al.,* 2008b). One of the main reasons for harmonization is the increasing prevalence in the harmonization of other aspects of trade and industry between countries (Vincent, 1998). However, it is said that full international harmonization is unlikely and an "intermediate harmonization" is proposed by Vincent (1998). This focuses on national lists of OELs that are based on national considerations but accompanied by common international criteria and methods.

It is now 14 years after Vincent (1998) has proposed at least partial harmonization and only minor changes has occurred such as the attempts made by the EU. Harmonization seems to set OELs at higher levels instead of the trend of OELs becoming lower over time and this is directly in contrast with the idea of setting OELs that are more efficient in protecting human health (Schenk *et al.*, 2008a). Nevertheless transparency of OELs is encouraged by many occupational hygiene professionals (Schenk *et al*.,2008b; Ding *et al*.,2011; Schenk and Johanson, 2011).

2.7 Different countries and standard setting authorities

The processes and characteristics of the different authorities and standard setters for both the developed and developing countries used in this study are summarized in Tables 1 and 2. These tables can further aid in the understanding of the different terminology used by different countries in able to refer to their OELs and whether the list of OELs are legally enforceable.

2.7.1 South Africa as focus area

South Africa is a developing country, which per definition means it is a country with a relatively low standard of living, undeveloped industrial base, and moderate to low Human Development Index (HDI).As mining and mining-related industries are some of the most prevalent industries in South Africa, occupational lung diseases due to exposure to coal, silica and asbestos are a big concern. A literature review done on the exposure in the mining industries concludes that it is necessary to prevent and control exposure of workers in order to reduce the incidence of occupational lung diseases (Ross and Murray, 2004; Wendell, 2012). However, mining is not the only industry of concern in South Africa as all of the non-mining industries also rely on the use of OELs to control exposure to HCSs. Provision is made for both general industries and the mining industries independentlyin South Africa.

For the general industries OELs are set by technical committees under the auspices of the Department of Labour and the regulations and are authorized by Act No. 85 of the 1993 Occupational Health and Safety Act (OHS-Act). These OELs are based on the UK values that were adopted in 1995 and they are described in the Hazardous Chemical Substances Regulations (HCSR) (Annexure 1 of OHS-Act). They are listed in two tables, Table 1 and 2 of the annexure mentioned above. South African HCSR characterises OELs in two groups, recommended occupational exposure limits (OEL-RL) and control occupational exposure limits (OEL-CL). Recommended limits are health based concentrations mostly derived from the most recent scientific data. These set thresholds values for exposure below which no detrimental effects are expected for the given substance over a specific period of time, usually an 8 hour work shift. Control limits however, take into account factors such as socio-economical and technical feasibility when setting a limit (South African Department of Labour, 1995).

Exposure to substances with an OEL-CL concentration must be kept as low as possible under the limit that is set (South Africa Department of Labour, 1995). OEL-CL are listed in Table 1 and relate to more toxic or potent HCSs such as carcinogens, and Table 2 contains OEL-RL. Whereas the OELs for the mining industries are set and implemented by the Department of Minerals and Resources and described in the Mine Health and Safety Act (1996) Regulation 22.9 (MHSR)of 2006 (South African Department of Labour, 1995; Department of Minerals and Resources, 1996; Brandys and Brandys, 2008).The MHSR was updated and revised in 2005 by the Mining Occupational Health Committee (MOHAC).The revision process of the MHSR was generally influenced by ACGIH and NIOSH (South African Department of Minerals and Resources, 1996).

At this point it is important to note the date of revision of South African OELs in 1995 as stated in Table 1. This is of major concern due to the fact that OELs decrease as they are revised (Hansson, 1997; Schenk and Johanson, 2011). The OELs listed in the HCSR of South Africa was implemented in 1995 and only a few amendments have been made since. The South African Department of Labour is currently in the process of revising the OELs and therefore it further emphasizes the significance of comparing current OELs with those of developed and leading trend setting countries in the world. Of further interest would be a comparison with other rapidly developing BRIC-countries.

2.7.2 Developed countries

There are very few countries that set OELs independently as many countries and jurisdictions are strongly influenced by leading trend setters such as, the United Kingdom (UK) Health and Safety Executive (HSE), German Deutsche Forschungsgemeinschaft (DFG) and United States of America (USA) ACGIH (Shuker*et al*., 2007).

The developed countries and jurisdictions that are reviewed in this study include: Australia,British Columbia (Canada), Finland, Germany,Japan, Sweden, UK and USA. The MHSR of South Africa was also included as it can provide valuable information regarding the divergence on a national level.

2.7.2.1 Australia

Australia lists their OELs referred to as exposure standards. The National Occupational Health and Safety (OHS) Commission Act of 1985 established the National Occupational Safety and Health Commission. This commission sets the OHS Standard for workplaces and the standards only become legally enforceable once they are adopted by the individual States and Territories. Each state is individually responsible for enforcing health and safety laws. The OELs are developed by the Exposure Standards Working Experts Group and their recommendations (guidance standards) are considered and then implemented when adopted as exposure standards (Brandys and Brandys, 2008; Work Safe Australia, 2011).

2.7.2.2 British Columbia (Canada)

In Canada there are 13 provinces each of which has their own safety and health regulations. The authority that therefore set the OELs in Canada depends on the specific province in question. Included in this study is British Columbia: permissible concentrations of airborne contaminants are referred to in Occupational Health and Safety Regulations of 1976 (B.C. Reg 296/76) under the implementation of The Workers Compensation Act (R.S.B.C 1979, c. 437). The Workers Compensation Board or as they are now called WorkSafe British Columbia (WorkSafe BC) have active committees that study and revise limits set in the province.

The Occupational Exposure Limit Review Committee makes the recommendations from which a decision of implementation is made. OELs set by British Columbia is strongly influenced by ACGIH TLVs and they adopted these values in 1995 (Brandys and Brandys, 2008) but exceptions were made for some chemicals (The Workers Compensation Act, 1979).

2.7.2.3 Finland

Health and safety in Finland is regulated by the Ministry of Social Affairs and Health. As part of the Ministry the Department of Occupational Safety and Health is responsible for all issues concerning the establishment and implementation of OELs. This department also has an Advisory Committee on Chemicals that establishes OELs. The first list of OELs from Finland was based on the ACGIH's TLVs in the

1960's. Since then Finland has developed new exposure limits called "Haitalliseksitunnetutpitoisuuder" (HTP values). The OELs are legally enforced by The Occupational Safety and Health Inspectorates under conditions defined by the Labour Inspection Act (Brandys and Brandys, 2008; Ding *et al.,* 2011; Social-ochhälsovårdsministeriet, 2011).

2.7.2.4 Germany

Germany is known to have the most advanced system of setting OELs due to the fact that they set scientific and health based OELs rather than technical and economically feasible OELs (Ding *et al*., 2011). The OELs of Germany are called Technically-feasible Guidance Concentrations ["TechnisheRichtkonzentrationen" (TRK)]. These relate to the control of carcinogenic and mutagenic substances. The organizations that are responsible for setting OELs in Germany are:The German Research Foundation ["DeutsheForshungsgemeinschaft" (DFG)] as well as the Committee on Hazardous Chemical Substances ["AusschussfürGefahrstoffe" (AGS)].The Advisory Group on Toxicology ("BeraterkreisToxikologie") recommends a health based OEL to the AGS. The AGS then recommends these OELs to the Ministry of Labour and Social Affairs who then includes the limits in the Technical Rules (TRGS 900). Supervision and enforcement of the final OELs set is the task of The Federal Ministry of Labour and Social Affairs (AusschussfürGefahrstoffe, 2006; Brandys and Brandys, 2008; Ding *et al*., 2011).

2.7.2.5 Japan

The Japan Society of Occupational Health (JSOH) is responsible for setting the reference values for OELs in Japan. The Ministry of Health Safety and Labour implement OELs recommended by JSOH and they then become legally binding. The OELs are revised and published annually in the Japanese Journal of Industrial Health (Brandys and Brandys, 2008; Ding *et al.,* 2011; Japan Society for Occupational Health, 2011).

2.7.2.6 Sweden

The Swedish Work Environment Authority (SWEA) is the authority that establishes the OELs for Sweden with the empowerment of the Work Environment Ordinance (SFS 1977: 1166). The OELs are legally enforced by the Work Environment Act - Arbetsmiljölagen, SFS- (Atividades e operacöesinsalubres, 1975)and exposure is thought to be kept as far below the exposure limit as possible. The Criteria Group of the National Institute of Working Life (Kriterigruppenförhygieniskagransvärde) draws up a consensus after reviewing scientific and toxicological literature in order to establish a list of OELs. The Swedish OELs are referred to as NGVs (Nivågränsvärde) of their 8-hour TWA (Brandys and Brandys, 2008; The Swedish Work Environment Authority, 2011).

2.7.2.7 United Kingdom

The UK has health based occupational exposure standards functioning under the Control of Substances Hazardous to Health Regulations (COSHH) (Brandys and Brandys, 2008). The standards are updated and revised every two to three years and are called Workplace Exposure Standards. The Health and Safety Commission’s Advisory Committee on Toxic Substances (ACTS) is responsible for recommending new OELs or revising existing OELs. After the ACTS have approved the OELs they are endorsed by the Health and Safety Commission (HSC). The Standards are then legally enforced and supervised by the Health and Safety Executive (HSE) (Brandys and Brandys, 2008; Ding *et al*., 2011).

2.7.2.8United States of America

Legally exposure to HCSsin the USA, is regulated by The Occupational Safety and Health Administration (OSHA), and the OELs are referred to as Permissible Exposure Limits (PELs). The current OSHA PELs were adopted from the ACGIH TLVs of 1968 and OSHA has updated only 30 HCSs OELs since the implementation of the OSH Act in 1970. Originally the National Institute of Safety and Health was responsible for developing and recommending new exposure limits to OSHA but their federal funding was cut and no new recommendations have been made for more than 15 years. OSHA is responsible for the enforcement of the health and safety regulations.

However some states may choose to use other list of OELs outside of the federal programme as long as the minimum stated by OSHA is adhered to (Occupational Safety and Health Administration, 1970; Brandys and Brandys, 2008).

The American Conference of Governmental Industrial Hygienists (ACGIH) is an independent authority of the US and sets OELs trademarked as Threshold Limit Values (TLVs). The ACGIH has two active committees that develop and revise their TLVs. This is done annually and published in their own booklets of ACGIH TLVs ® (Brandys and Brandys, 2008). The committees study and review the latest scientific data both published and unpublished. These limits are not legally enforceable unless adopted by individual states and set into action by the specific regulations of the state or country (American Conference of Governmental Industrial Hygienists, 2012)

2.7.3 Developing countries (BRICS)

BRICS is an acronym that refers to the economies of Brazil, Russia, India, China and South Africa. All of these members are developing or newly industrialized countries that are known for their growing economies and influences. The five BRICS countries are distinguished from a host of other promising emerging markets by their demographic and economic potential to rank among the world's largest and most influential economies in the 21st century (Ministry of Finance, Government of India 2012). Each one of the above mentioned countries set and implements their OELs by different methods and are based on different criteria. The information concerning the authorities responsible for establishing and implementing OELs in these countries is summarized in Table 2.

2.8 Leading trend setting authorities

It is clear from history, development as well as from the information in Tables 1 and 2 that the ACGIH plays one of the most influential and leading roles when it comes to setting OELs. Many countries make use of ACGIH's TLVs as a starting point and other countries merely adopt the values that ACGIH has set for their country. A possible reason for this is that these limits are revised and issued annually. Despite the criticism, many claim that ACGIH's TLV's are one of the few remaining resources for employers and employees seeking to make their workplaces safer (Monforton, 2012). It sets a worldwide platform that can be used to evaluate exposure of workers and revision of national lists of standards.

The use of EU lists of OELs is also a common phenomenon in many countries and jurisdictions (Schenk *et al.*, 2008b). With the implementation of REACH as previously noted, this influence is expected to become more substantial in the future. Currently the benefits of this regulation are still diminutive, but it will gradually become more influential as more substances are phased into the REACH system.

Table 1: Characteristics and information of OEL setting systems

Country/ Jurisdiction	Standard Setting Organization	Designation of OEL	Legally Binding Status	Source of Influence	Date of publication
Australia	Work Health and Safety (WHS) (Work Health and Safety Act)	Exposure standards	Application is mandatory, Section 19 of WHS Act prescribes the duties (Guidance standards are adopted by state)	ACGIH also Germany, Netherlands	2011
British Columbia (Canada)	WorkSafeBC (Workers Compensation Act, 1979)	Exposure Limits	Administered by Industrial Health and Safety Regulations and industry must comply	ACGIH	2012
Finland	Finnish Ministry of Social Affairs and Health	HTP-values (Concentration Known to be Harmful)	Legally enforced by the Ministry of Social Affairs and Health	ACGIH EU	2011
Germany	Committee on Hazardous Substances (AGS)	Technical Guidance concentrations (TRGS 900)	German Federal Minister of Labour and Social Affairs makes the values legally binding in their appropriate form.	ACGIH	2009
Japan	Japan Society of Occupational Health (JSOH)	Occupational Exposure limits for chemical substances	Recommended OELs by the JSOH have no legal force but becomes legally enforceable when implemented by The Ministry of Health Safety and Labour (MHLW)	ACGIH	2010

South Africa	South African Department of Labour (OHS-Act) (HCSR,1995)	Occupational exposure limits	Enforced by the South African Department of Labour and all non-mining industries must comply	Adopted UK standards in 1993	1995[a]
	South African Department of Minerals and Resources (MHSR 22.9)	Occupational exposure limits for airborne pollutants	Federally enforced bySouth African Department of Minerals and Resources (formally Energy) and all mining and mine-related industries	ACGIH NIOSH	2006 [b]
Sweden	The Swedish Work Environment Authority (SWEA)	Occupational Exposure Limit Values and Measure against Air Contaminants (AFS 2011:18)	Legally enforced by the Swedish Work Environment Inspection (Arbetsmiljöinspektionen)	ACGIH EU	2011
UK	Health and Safety Commission (HSC)	Workplace Exposure Limits	Authority that ensures enforcement is the Health and Safety Executive (HSE)	ACGIH EU	2011
USA	American Conference of Governmental Industrial Hygienists (ACGIH)	Threshold Limits Values (TLV) for Chemical Substances	Not legally enforceable but is adopted and used as a guideline by many different countries	ACGIH Committees	2012
	Occupational Health and Safety Administration (OSHA)	Permissible Exposure Limits (PEL) for Airborne Contaminants	Implemented by Occupational Safety and Health Act(OSH Act) the standard set by this authority is legally enforceable (1970)	ACGIH NIOSH	1970

[a]Only a few amendments have been made to the HCSRfrom 1995.
[b]The MHSR was updated and revised in 2005 and published in 2006 by the Mining Occupational Health Committee (MOHAC)

Table 2: Characteristics of BRICS (developing) countries, excluding South Africa

Country/ Jurisdiction	Standard Setting Organization	Designation of OEL	Legally Binding Status	Source of Influence	Date of publication
Brazil	Ministry of Labour Brazil	Tolerance Limits for chemical substances	Legally enforced by the Brazilian Ministry of Labour	ACGIH	1975
Russia	Russian Federation Department of Sanitary and Epidemiological Surveillance	Exposure Limits of harmful substances in the air of the working area	These levels are made legally enforceable to all by the Russian Ministry of Justice	Russia [a]	2008
India	The Ministry of Labour and Employment (Section 41F of Factories Act)	Permissible limits of Exposure of chemicals and toxic substances	Federally enforced by The Ministry of Labour and Employment	–[b] –[c]	2006/1956[d]
China	The National Committee of Occupational Health Standards Setting (NCOHSS) Ministry of Health	Occupational exposure limits for hazardous agents in the workplace (GBZ)	Legally enforced by the Ministry of Labour in China	ACGIH Germany Russia JSOH	2007

[a]Russia has the list with the most number of substances regulated influenced by entirely toxicological data Dobbie, J, personal communication, July 30; Russian Federation Department of Sanitary and Epidemiological Surveillance. 2007)
[b]Unknown or not available
[c]Multinational companies and large Indian companies that practice occupational hygiene in India use the ACGIH TLV’s
[d] Uncertaintyexists on the updated status of India’s OELs, some sources state2006 and the official document refers to the Factory Act of 1956.

2.9 Conclusion

OELs are one of the most basic and essential tools that aid in protecting workers exposed to HCSs. The processes used to set and implement OELs vary between countries and jurisdictions due to of various factors. The factors that play a key role are determined individually by each county or jurisdiction. Large discrepancies in the OELs set by different countries accentuate the need for harmonization of OELs. How effective an OEL is can be determined by a comparison based on different aspects between different countries. The following two chapters consist of articles that compare South African OELs in HCSR with MHSR, developed and other developing countries and jurisdictions.

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Chapter 3: Article 1

Comparison of South African occupational exposure limits for hazardous chemical substances with those of other countries.

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Abstract

Introduction: Many divergences have been reported over the years when it comes to the topic of setting and implementing occupational exposure limits (OELs). The aim of this study is to compare South African OELs with those of developed countries with regards to substance selections and overall level of OELs set for hazardous chemical substances (HCSs).

Methodology: The OELs established by the Mine Health and Safety Regulations (MHSR) and 9 different standard setting countries and jurisdictions, all of which are from developed countries were compared to the South African Hazardous Chemical Substance Regulations (HCSR). The OELs were compared based on two aspects, selection of HCSs and the level at which the OELs for HCSs are set. The final database used for comparison consisted of 1110 HCSs. The comparison was based on the number of HCSs that were listed by each country with a complete comparison list and a standard comparison list of the 76 HCSs. Further comparison was done on the overall level at which the OELs are set by using the geometric means method. The geometric means methods for both the standard comparison list and the complete comparison list was analysed by a paired t-test and a Pearson correlation.

Results: There are large variations in substance identification and selection between the 11 countries and jurisdictions and a large number of HCSs are regulated uniquely. A total number of 231 HCSs are uniquely regulated by only one country/jurisdiction and only 76 of all 1110 HCSs was listed by all 11 countries and jurisdictions. The highest number of overlapping substances between lists are the 583 HCSs that are listed by both the South African HCSR and the South African Mine Health and Safety Regulations (MHSR). Japan had the lowest number of overlapping HCSs (193) when compared to HCSR. The average overall level of OELs differs substantially between countries. The American Conference of Governmental Industrial Hygienists (ACGIH) having the lowest, and Occupational Safety and Health Act (OSHA) having the highest overall level of OELs when compared to the South African HCSR.

Discussion: There are large differences in both the selection of HCSs and the level at which different countries and jurisdictions set their OELs. A multitude of different factors are responsible for large discrepancies existing between countries.

Factors include variations in scientific reasoning, the risk acceptance of the negative impact that various HCSs might induce and the time lags that countries have between updates. Further differences may be explained by the difference in consideration of socio-economical and practical feasibility of an OEL and the predominant industries in a country.

Conclusion: The large variations that exist between OELs of different countries is confirmed by the finding of the study. When compared to the developed countries the number of HCSs uniquely regulated by South African HCSR was few. South Africa, as a developing country, has higher overall level of OELs than other developed countries included in this study. These findings indicate a low level of adequacy of South African OELs in the HCSR, indicating the inadequacy to control exposure and hence to protect the South African workforce against adverse health effects.

Key words: occupational exposure limits, comparison, developed countries, hazardous chemical substances, South Africa

3.1 Introduction

The use of different hazardous chemical substances (HCSs) in the workplace poses certain risks and dangers to human health. Occupational Exposure Limits (OELs) set by countries and other jurisdictions help identify and control exposure to these risks and dangers in the workplace. However, not all countries and jurisdictions who set these limits use the same standardized methods and there is therefore variation in the way these limits are set and the concentration at which they are set (Schenk *et al*., 2008b). An OEL is the concentration of a workplace hazard that most workers can be exposed to without harming their health or posing risks for adverse effects (Rappaport and Kupper, 2008). OELs have been used since the early 1900's and most industrialised countries have a national authority or organisation issuing their own lists of OELs (Schenk *et al.*, 2008a; Paustenbach *et al*., 2011). The first list of standards for exposure to HCSs in the industry was called Maximum Allowable Concentration (MAC) values. Thereafter the American Conference of Governmental Industrial Hygienists (ACGIH) introduced Threshold Limit Values (TLV) in 1956 (Schenk *et al*., 2008a). Many jurisdictions follow the lead of prominent trend setters such as: United Kingdom (UK) Health and Safety Executive (HSE), German Deutsche Forschungsgemeinschaft (DFG) and United States of America (USA) ACGIH (Shuker *et al*., 2007). The ACGIH's TLVs are probably the most influential of them all as many countries make use of these limits as a starting point and others merely adopt the values (Ding *et al.*, 2011; Schenk and Johanson, 2011).

For exposure to airborne contaminants, three types of OELs are commonly used: time-weighted average occupational exposure limits (TWA), short term exposure limits (STEL) and ceiling limits (CL). The most common type used is the TWA that lists concentrations that workers may be exposed to for an 8 hour working day. OELs are set to primarily protect a worker's health and therefore the goal should be to keep exposure as low as reasonably possible. This is not always possible or practical in all the industries and as a result there are numerous methods used to determine the concentration of a HCS that is safe to the majority of workers (Klonne, 2003; Adkins *et al*., 2009).

The final concentration of the OELs set for HCSs, however does not only rely on the consideration of health effects but also on other socio-economical and technical aspects defining the OELs feasibility (Ding *et al*., 2011; Schenk and Johanson, 2011). It are these aspects that have a major influence on how OELs are set by different countries and gives rise to considerably different outcomes and processes of setting and implementing an OEL. The time lags between updates for the lists of OELs has previously been identified as one of the most influential reasons for the lack of standardized OEL values within various jurisdictions and emphasizes the need to regularly amend and update OELs (Schenk and Johanson, 2010). It has been shown that OELs appear to have decreased gradually over time if they are revised (Hansson, 1997; Schenk and Johanson, 2011). Revisions form an important part of the process of setting and implementing an OEL value.

There have been numerous proposals for standardized approaches between countries to improve these differences (Ding *et al.,* 2011). Nevertheless harmonization has not yet been possible. The constant on-going effort to harmonize the OELs and the methods used to identify and set an OEL is based on the disparity of these two aspects. Firstly, the determination of how safe an OEL is, this is called the health based or scientific aspect. Secondly, how affordable and practical it is to implement an OEL. With the rapid development of economic globalization there is a need for international harmonization for substance selection and setting of OELs (Liang *et al.,* 2006). Hansson and Ruden (2006) states that studies of OELs indicate large and unsystematic differences between decisions made and values set for HCSs with similar adverse health effects. This further stresses the need for more standardization.

Comparison of South Africa's OELs for HCSs with other developed countries and jurisdictions can help to determine to what extent South Africa's OELs are considered adequate. The South African Department of Labour, under the guidance of Minister of Labour, regulates the Hazardous Chemical Substances Regulations (HCSR) (South African Department of Labour, 1995). These lists of OELs in the HCSR are set for the non-mining or general industries, whereas the OELs for the mining industries are set and implemented by the Department of Minerals and Resources and are stipulated in the Mine Health and Safety Act (MHSA) Regulation 22.9 of 2006 and will henceforth be referred to as the Mine Health and Safety Regulations (MHSR) (South African Department of Minerals and Resources, 1996; Brandys and Brandys, 2008).

In this paper we will systematically compare South African OELs as listed in HCSR with nine developed countries and jurisdictions: Australia, Sweden, USA (ACGIH and OSHA), UK, Finland, British Columbia (Canada), Japan and Germany with South Africa's two lists. The MHSR of South Africa is also included as it can provide valuable information of the difference there exists within the national regulatory authorities of South Africa. Evaluating and comparing the lists of OELs can help determine the state of South African OELs and whether there is a significant difference in the OELs. Our aim is to compare South African lists of OELs to the developed countries and jurisdictions according to two main variables: coverage of individual HCSs referring to the number of HCSs listed by each country and the overall level (concentration) of OELs set for the different HCSs.

Table 1: Characteristics and information of OEL setting systems

Country/ Jurisdiction	Standard Setting Organization	Designation of OEL	Legally Binding Status	Source of Influence	Date of publication
Australia	Work Health and Safety (WHS) (Work Health and Safety Act)	Exposure standards	Application is mandatory, Section 19 of WHS Act prescribes the duties (Guidance standards are adopted by state)	ACGIH also Germany, Netherlands	2011
British Columbia (Canada)	WorkSafeBC (Workers Compensation Act)	Exposure Limits	Administered by Industrial Health and Safety Regulations and industry must comply	ACGIH	2012
Finland	Finnish Ministry of Social Affairs and Health	HTP-values (Concentration Known to be Harmful)	Legally enforced by the Ministry of Social Affairs and Health	ACGIH EU	2011
Germany	Committee on Hazardous Substances (AGS)	Technical Guidance concentrations (TRGS 900)	German Federal Minister of Labour and Social Affairs makes the values legally binding in their appropriate form.	ACGIH	2009
Japan	Japan Society of Occupational Health (JSOH)	Occupational Exposure limits for chemical substances	Recommended OELs by the JSOH have no legal force but becomes legally enforceable when implemented by The Ministry of Health Safety and Labour (MHLW)	ACGIH	2010

South Africa	South African Department of Labour (OHS-Act) (HCSR,1995)	Occupational exposure limits	Enforced by the South African Department of Labour and all non-mining industries must comply	Adopted UK standards in 1993	1995 [a]
	South African Department of Minerals and Resources (MHSR 22.9)	Occupational exposure limits for airborne pollutants	Federally enforced by South African Department of Minerals and Resources (formally Energy) and all mining and mine-related industries	ACGIH NIOSH	2006 [b]
Sweden	The Swedish Work Environment Authority (SWEA)	Occupational Exposure Limit Values and Measure against Air Contaminants (AFS 2011:18)	Legally enforced by the Swedish Work Environment Inspection (Arbetsmiljöinspektionen)	ACGIH EU	2011
UK	Health and Safety Commission (HSC)	Workplace Exposure Limits	Authority that ensures enforcement is the Health and Safety Executive (HSE)	ACGIH EU	2011
USA	American Conference of Governmental Industrial Hygienists (ACGIH)	Threshold Limits Values (TLV) for Chemical Substances	Not legally enforceable but is adopted and used as a guideline by many different countries	ACGIH Committees	2012
	Occupational Health and Safety Administration (OSHA)	Permissible Exposure Limits (PEL) for Airborne Contaminants	Implemented by Occupational Safety and Health Act (OSH Act) the standard set by this authority is legally enforceable (1970)	ACGIH NIOSH	1970

[a] Only a few amendments have been made to the HCSR from 1995.
[b] The MHSR was updated and revised in 2005 and promulgated in 2006 by the Mining Occupational Health Committee (MOHAC)

3.2 Methods

3.2.1 Lists of OELs

The different countries and jurisdictions' most recent published lists of OELs were systematically collected, either by websites or through personal communication with the relevant parties and representatives. The selection of countries and jurisdiction was based not only on availability of data but also on those countries most dominant in the literature and from personal experience. The language barrier was also another factor taken into consideration in the selection process. The regulatory agencies' lists of OELs obtained were: Australia, British Columbia (Canada), Finland, Germany, Japan, UK, USA (ACGIH and OSHA) and Sweden. The MHSR of South Africa was also included as it can provide valuable information regarding the disparity of the OEL setting processes within South Africa. The following data was collected for each standard setting authority, and is listed in Table 1: the standard setting organization, the designation of their OELs, legally binding status whether legally enforceable, the source by which the authority is most influenced by if any, and finally the date of publication.

A CAS (Chemical Abstracts Service) number is a unique numerical combination assigned to each chemical substance that aids in correctly identifying a HCS. Previous studies done by Schenk *et al*. (2008a), Schenk and Johanson (2011) and Ding *et a*l. (2011) on the comparison of OELs between countries and jurisdictions only included HCSs that were assigned a CAS number. CAS numbers are absent from the South African HCSR, which complicated comparison and previous studies methodology could not be merely adopted. Thus a list of all possible synonyms and basic chemical structures was used throughout the collection of different OELs to enable the correct identification and pairing of a specific HCS. The use of synonyms and chemical structures for identification ascertains that all chemicals and mixtures were included. In the South African lists of OELs there were synonyms (duplicates) of HCSs and they were first removed and noted before commencing with the comparison. All the synonyms (duplicates) that were removed from the database are shown in the supplementary material at the end of the article.

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3.2.2 Database used

A spreadsheet was used to systematically complete the 8 hour TWA OELs set by all of the different countries and jurisdictions using South Africa as the standard or basic comparison list. The final database used in this study consisted of the OELs from 11 countries and/or jurisdictions. HCSs were listed based on their chemical names and the correct CAS number was selected and listed accordingly to enable correct pairing of HCSs with the rest of the countries and jurisdictions.

Many OELs for HCSs are listed in both ppm (parts per million) and mg/m^3 (milligrams per cubic meter). All of the OELs in this study were noted in mg/m^3 as this was the unit for which the least number of conversions was necessary and which occurred most in the different lists. Where necessary conversions were done from ppm to mg/m^3, by the following calculation as it was previously used in studies done to compare OELs (Schenk *et al*., 2008a; Ding *et al*., 2011; Schenk and Johanson, 2011):

Concentration (mg/m^3) = *(Concentration ppm)(molecular weight)/24.45*

The conversion equation was used at conditions that are standard at 25 ºC and 1 atmospheric pressure for all HCSs that were converted. For some of the HCSs for conversions could not be done. This is due to the fact that an exact molecular weight for the substance could not be obtained as the composition of some of the HCS varies (e.g. aliphatic hydrocarbons) and they were subsequently not included in the list.

For the HCSs that only have a short term exposure limit (STEL) the value was adjusted by conversion factors recommended by the ACGIH (Table 2) (Schenk *et al*., 2008a). The number of conversions for HCSs that only had a STEL was in the minority among the different sets of data.

Table 2: Factors for recalculating an 8 hour TWA average from a STEL value as suggested by ACGIH (Hansson, 1997; Schenk *et al*., 2008a)

TWA (*ppm or mg/m^3*)	C factor
$X \leq 1$	3
$1 < X \leq 10$	2
$10 < X \leq 100$	1.5
$100 < X \leq 1000$	1.25
$1000 < X$	1

When more than one OEL was given for a HCS (e.g. inhalable and respirable, groups of chemicals and their isomers) then both where included. The HCSs for which the OEL was allocated for different working conditions, for example ozone, the designated OEL for a country or jurisdiction was given to all of the subdivisions. The final database used in this study contained 1110 HCSs listed according to their CAS number and OELs.

3.2.3 Coverage and selection of substances

The comparison was done by comparing the similarity between South Africa's lists of OELs in the HCSR with the MHSR and each of the developed countries lists. Comparison was thus relative to South African HCSR. Not only the similarity of overlapping HCSs but also the number of HCSs uniquely regulated by each country or jurisdictions was compared. The presence of HCSs on both lists were counted as overlapping, whereas the absence from either of the lists, amounted to the number of HCSs uniquely regulated by the country or jurisdiction in question. The similarity in choice of substance selection between South Africa compared to the selection by the rest of the countries and jurisdiction were evaluated. As mentioned previously, every HCS listed was included even if there was more than one OEL for a HCS such as soluble and insoluble form. To furthermore compare coverage of HCSs we determined the number of countries which regulates each individual HCS thus obtaining information on the number of HCSs regulated only by one or a few countries or jurisdictions. This was done for each of the 1110 HCSs in the final database.

3.2.4 Statistical analysis

3.2.4.1 The geometric means method

Values of OELs in the list were compared statistically with the geometric means method. The method was first applied by Hansson (1997) and is used for the comparison of the overall level of complete lists of OELs (Schenk *et al*., 2008a; Ding *et al.*, 2011). For the comparison between two lists, of OELs the comparison should refer only to those HCSs that have OELs on both of the lists that are to be compared to one another (e.g. HCSR versus MHSR). The overlapping OELs yielded a complete, more comprehensive list for comparison. This is so that HCSs that are regulated by very few countries do not influence the average level that is calculated.

For comparison between all countries and jurisdictions, only the HCSs that were listed by all of the 11 countries and jurisdictions involved were included in this standard comparison list. The final standard comparison list that was used comprised of 76 and this list can be found in the supplementary material at the end of the article. The geometric mean was then determined for these ratios. A quotient between the values on the different lists (complete comparison list of two countries and the standard comparison list) for each HCS was determined as the best indicator of the difference between two lists.

The importance for the use of geometric means rather than arithmetic means or median can be emphasized by the following: the list values when determined with arithmetic means will be perceived as having a higher value depending on which list is used as a denominator. To illustrate this, consider the following example: List *A* and *B* both assigns OELs for three HCSs. List *A* allocates 20 ppm to substance I, 15 ppm to substance II and 10 ppm to substance III. On the other hand List *B* has set the OELs for the same HCSs at 200 ppm for substance I, 15 ppm for substance II and 1 ppm for substance III. The arithmetic means of ratios for *B/A* or *A/B* both equal 3.7 giving the impression that either *A* or *B* have set higher OELs irrespectively. In both these instances the geometric means of ratios equal 1 indicating that the overall level of the two lists does not differ (Schenk *et al*., 2008b; Ding *et al*., 2011).

A geometric means lower than 1 indicates that the list being compared has a lower overall level of OELs, whereas a geometric means value of above 1 indicates a higher overall level of OELs. By using the geometric means the ratios are more representative irrespective of their denominator.

3.2.4.2 t-test for comparison of geometric means methods

Further statistical analysis was done to determine whether there were significant differences between the standard comparison list and the complete comparison list used for the geometric means methods. This was done by conducting a paired t-test for the geometric means of the standard comparison list and the complete comparison list. A Pearson correlation was also used to analyse the data in order to establish whether there is a statistical significant agreement between the two lists. A p-value of smaller than or equal to 0.05 is considered to be significant.

3.3 Results

3.3.1 Comparison of OEL coverage

A list of 155 HCSs with synonyms (duplicates) names were identified and removed from the South African HCSR before the comparison on coverage of HCSs was done. These synonyms (duplicates) are listed in the supplementary material.

Coverage of HCSs by the different countries and jurisdictions is graphically illustrated in Figure 1. The number of HCSs overlapping between South Africa and the country or jurisdiction in question is shown along with unique substance coverage by each of the individual countries of jurisdictions. The similarity in coverage and selection of HCSs is the highest between South Africa’s HCSR and the MHSR having 583 overlapping HCSs. With the least number of overlaps (193) occurring between South Africa and Japan. Furthermore it indicates that the ACGIH and British Columbia (Canada) have the highest number of uniquely listed OELs when compared to the HCSR of South Africa.

Figure 2 illustrates the number of countries and jurisdictions that list each one of the 1110 HCSs, with 20.8% or 231 of the HCSs were listed by only one country or jurisdiction. Only 7% or 76 of the 1110 HCSs were listed by all 11 countries and jurisdictions.

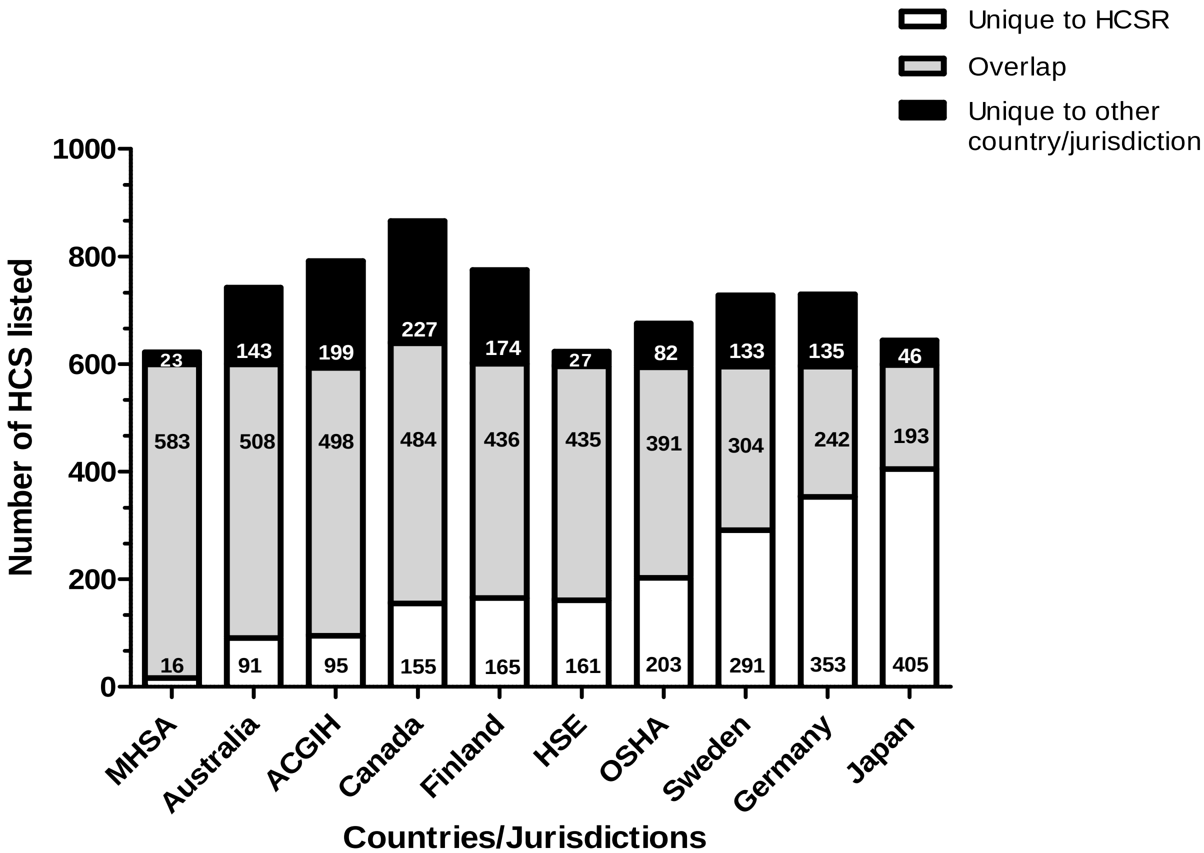

Figure 1: The disparity and similarity of coverage of HCSs between the different countries and jurisdictions when compared with HCSR. The numbers of overlapping HCSs are indicated in descending order.

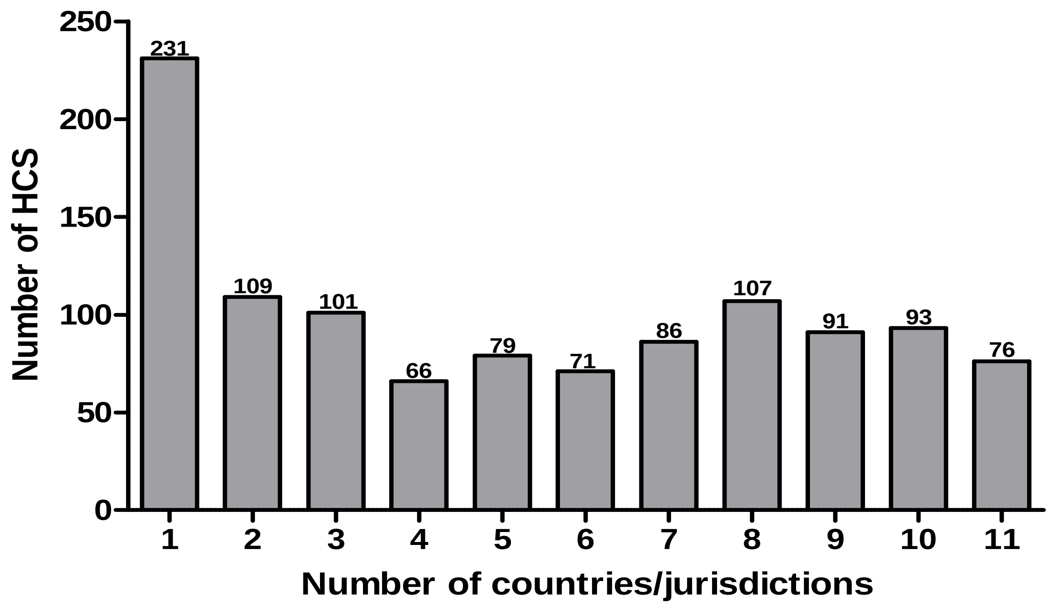

Figure 2: The number of HCSs and the number of countries and jurisdictions that have included the HCSs in the main comparison list in their list of OELs.

3.3.2 Levels of occupational exposure limits

The geometric means method is used to compare the overall levels of OELs from different countries and jurisdictions relative to the HCSR of South Africa. Both the standard comparison and the complete comparison list were used to indicate and compare the overall level of OELs for each individual country and jurisdiction. In Table 3, the geometric means of ratios based on both the standard comparison list (76 HCSs) and the complete comparison list of overlapping HCSs are listed (HCSR versus other developed country/jurisdiction). All of the geometric means of ratios are below 1, except for OSHA that has geometric means of 1.349 and 1.294 respectively.

Figure 3A illustrates the geometric means of ratios for the standard comparison list. Ratios are represented in ascending order with OSHA having the highest geometric means of ratios. ACGIH has the lowest geometric mean followed by Canada. Furthermore the results for the complete comparison list based on the higher number of overlapping HCSs are represented in Figure 3B. Sweden has the lowest value of geometric means but OSHA still has the highest value. Comparison between South African HCSR and MHSR results in geometric means values of 0.866 and 0.803 for the standard comparison and the complete comparison lists respectively.

Table 3: The geometric means of ratios based on both the standard comparison list and the complete list of overlapping HCSs, using South Africa HCSR as comparison list.

Country/Jurisdiction	Geometric mean (standard) [a]	Geometric mean [b] (complete)	No. of substances [c]
ACGIH	0.450	0.591	467
Australia	0.708	0.885	472
Canada	0.494	0.599	443
Finland	0.502	0.617	435
Germany	0.572	0.628	243
HSE	0.565	0.795	433
Japan	0.678	0.570	189
MHSR	0.866	0.805	563
OSHA	1.349	1.294	377
Sweden	0.503	0.487	285

[a] Geometric means of ratios based on the standard comparison list (76 substances HCS listed by all)
[b] Geometric means of ratios based on all the overlapping substances that were present between lists (HCSR versus other developed country/jurisdiction).
[c] Number of substances that the geometric means of ratio is based on complete comparison list (overlapping HCSs)

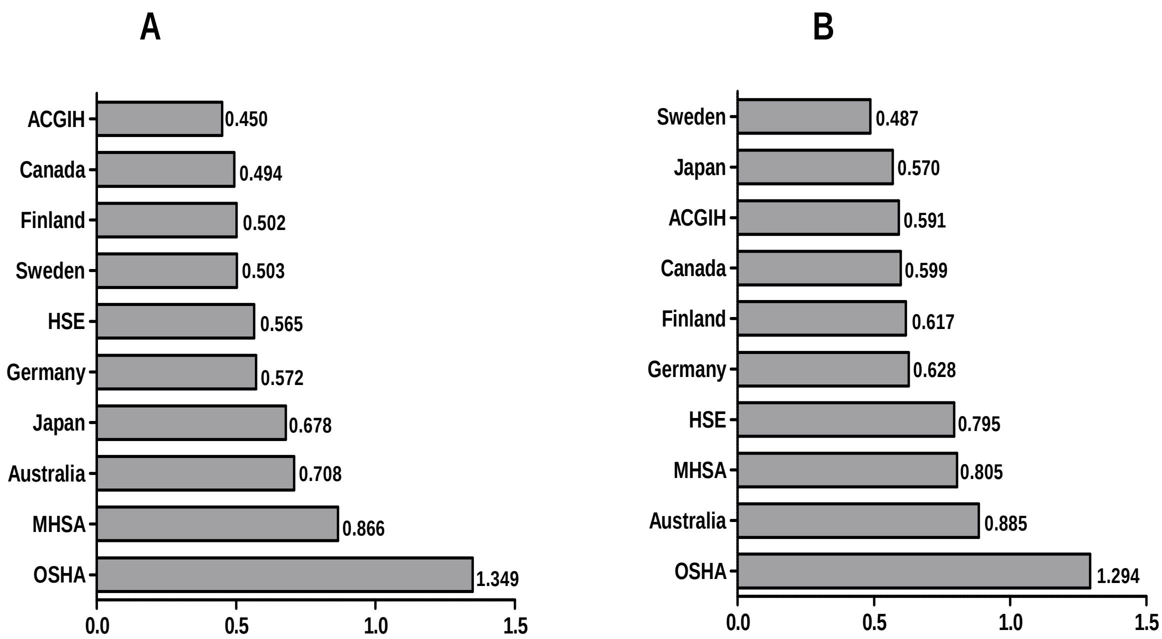

Figure 3: (A) The geometric means of ratios based on the standard comparison list compiled from the 76 HCSs present in all 11 countries/jurisdictions. **(B)** The geometric means of ratios are based on all of the overlapping HCSs between the HCSR and the other country or jurisdiction. Both figures represent the geometric means of ratios in ascending order.

3.3.3 Differences in lists used for comparison by geometric means methods

To determine whether there were significant differences between geometric means methods for the standard comparison list and the other complete comparison lists, a dependent t-test was conducted. The shorter list of 76 HCSs geometric means of ratios was compared to the geometric means of ratios of the complete comparison list. This was done to establish whether there was a difference in geometric means with the shorter standard comparison list and when all overlapping HCSs were included. A p-value of 0.138 indicated that there is no statistically significant difference between the geometric means methods of these two lists. A Pearson correlation indicated that there is a strong highly significant correlation between these two lists (r=0.908 and p=0.0003). Although the results from the geometric means of ratios may imply that the number of HCSs strongly influences the geometric means, the difference between the standard and complete lists are evidently small.

3.4 Discussion

South African OELs as contained in the HCSR were compared to those of the MHSR and other developed countries. Both the number of HCSs and the overall level were compared using South Africa HCSR as the base of all comparison done. South Africa has not yet been included in studies that have been done on the comparison of OELs between different countries and jurisdictions.

The findings of this study confirm the large differences that exist in substance identification and selection for OELs. This is indicated by the number of HCSs that are only regulated by one country or jurisdiction; the highest numbers of HCSs (20.8%) are regulated uniquely. Only a few HCSs are regulated by all of the countries and jurisdictions in the study, these amounts to 76 overlapping HCSs. Furthermore there were few HCSs regulated exclusively by South Africa when compared to the major standard setters such as ACGIH and Finland. From the results presented in this study it may seem that Finland has a smaller number of uniquely regulated OELs. This is due to the fact that they include a number of isomers for HCSs where as it is listed in the database used in this study as a group of HCSs. The use of groups of HCSs rather than all possible isomers made identification and paring of the substances more consistent between South Africa and all of the other countries. Occupational exposure limits are set based on the use of different data and methods. As expected there are therefore substantial differences in the OELs of different countries and jurisdictions (Schenk *et al*, 2007; Ding *et al*., 2011; Schenk and Johanson, 2011). Various explanations are proposed for these differences, including scientific reasons, time lags between updates and differences in risk acceptance of the harmful effects that a HCS may induce (Ding *et al.*, 2011). Variations can also be explained by the difference in considerations of economic, technological and other factors. Differences in predominant industries and exposure conditions are also important factors, the industrial structure of a country, will make provision for the HCSs most prevalent and harmful (Ding *et al.,* 2011). The result of the study sets South African OELs among those of the various developed countries and jurisdictions. The final database included 1110 HCSs; most of the countries only regulate a few hundred of these HCSs.

The overlapping HCSs are the highest between MHSR and South African HCSR indicating the national similarity and status. Both these jurisdictions are within the same country and relate to the same workforce, regardless of the fact that the MHSR only apply to the mining industries there is still large agreements in the HCSs selection. The similarity of industries and the working conditions in the nationalities can be partly responsible for the similarity in the selection of HCSs (Ding *et al*., 2011). The MHSR does, however, have more uniquely regulated OELs, this may be attributed to the difference in industries as there are different HCSs that need to be regulated in the mining industry compared to the general industry. The study does not include the evaluation of the processes used by each country or jurisdiction and thus no conclusion can be made on the factors that had an influence on the identification and selection of HCSs. Evaluation of the different countries and jurisdiction documentations containing this information was not possible due to the lack of transparency, non-accessibility and language. This problem has occurred in previous studies done on comparison of OELs between different countries (Schenk *et al*., 2008a; Ding *et al*., 2011).

The geometric means of ratios for all countries and jurisdictions (except OSHA) has a value below 1, concluding that all of the countries and jurisdictions have lower overall OEL levels than the South African HCSR. OSHA has the highest over-all level of OELs. The current high level of OSHA's PELs is attributed to the regulatory machinery used and its last update only occurred in 1970 (Schenk *et al.*, 2008a). Finland, ACGIH and Japan (JSOH) set OELs that claim to have a purely health-based approach for setting OELs (Brandys and Brandys, 2008). Finland's OELs contain concentrations of HCSs which are hazardous to human health, these limits are not mandatory (Social- och hälsovårdsministeriet, 2011), but are used to assess work exposure and air quality, whereas other countries and jurisdictions contain concentrations that are safe for exposure in an 8 hour workday without presenting adverse health effects (Ding *et al*., 2011). The rational that lower OELs are more protective of human health is confirmed by the low overall levels of OELs set by the ACGIH, JSOH and Finland that have health based OELs. The lower the level of OELs in a country the more they will be able to protect the workers against the adverse health effects that HCSs exposure may induce, whereas higher OELs may allow excessive exposure to HCSs causing more negative health effects.

The OELs in HCSR have a substantially higher overall level. This further emphasizes the fact that the HCSR as adopted from the UK, have been last updated in 1995 and only as few amendments have been made since. As stated previously OELs seem to decrease as they are revised, thus this can be a possible explanation for the high level of these limits (Schenk and Johanson, 2010). Schenk *et al.* (2008a) stated that the rate of revision of list of OELs have decreased over the years and that possible explanations for this might be that the higher level of OELs that there once was has already been diminished and that when OELs are lowered beyond a certain point the health benefits are no longer defensible against the high economic costs. The study of the level of OELs does not allow any conclusions to be made on the process or the actual working conditions in the country or jurisdiction (Ding *et al*., 2011). The strong influence of the ACGIH is not without cause as their overall level of exposure limits is the lowest when compared with the standard comparison list and among the lowest three in the complete comparison as seen in Figure 3A and B. The lower the overall level of OELs are, the less practical they become to implement. Not all countries and jurisdictions have the necessary resources to implement and sustain such low OEL levels.

Our results from the comparison by geometric means of ratios for both the standard comparison list and the complete comparison list found that there were no significant differences in the geometric means found by these two lists when analysed by paired t-tests. Rather than differences, a strong significant correlation was found, highlighting the potential use of such a standard comparison list containing HCSs listed by all of the countries and jurisdictions. Both the standard comparison list and the complete comparison list was a good indication of the overall level of OELs in a country or jurisdiction relative to South African HCSR. A more in-depth investigation into the processes used by these different countries and jurisdictions may give a more detailed description of why these large variations do exist as documentation may provide information of the intended level of protection by the OELs set (Schenk *et al*., 2008a).

3.5 Conclusion

The results of this study indicate the large and unsystematic setting of OELs among countries and further underline the difference between developed countries and South Africa as a developing country. Large discrepancies exist in the selection of HCSs between countries and jurisdictions. There might also be controversy in the science leading to different conclusions being drawn regarding various HCSs (Schenk *et al*., 2008a). The OELs as contained in the HCSR have an overall higher level of OELs and a weak prevalence of uniquely regulated OELs when compared to developed countries and jurisdictions. Both these aspects indicate that South African OELs in HCSR are inadequate to some extent to control exposure and protecting the South African workforce from adverse health effects resulting from HCSs exposure.

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3.7 Supplementary material

Table 1: List of synonyms that occured in the South African Hazardous Chemical Substances Regulations. Chemicals are listed in alphabetical order

Hazardous chemical substance listed	**Name of synonym removed**
1,2 -Dibromoethane (CL)	Ethylene dibromide (RL)
2 Ethoxyethanol CL	Ethylene glycol monoethyl ether
1,1,1-Trichloroethane(CL)	Methyl chloroform (RL)
1,1-Dichloroethane	Ethylidene dichloride
1,2-Diaminoethane	Ethylenediamine
1,2-Dichloroethane	Ethylene dichloride
1,2-Epoxy-4-epoxyethyl cyclohexane	Vinyl cyclohexene dioxide
1-Chloro-2,3-epoxypropane (epichlorohydrin)	Epichlorohydrin
1-Methoxy propan-2-ol	Propylene glycol monomethyl ethe
2,2 Bis (p-methoxyphenyl)-1,1,1-trichloroethane	DMDT
2,2 Bis (p-methoxyphenyl)-1,1,1-trichloroethane (DMDT)	Methoxychlor

2,2'-Diaminodiethylamine	Diethylamine triamine
2,2'Dichloro-4,4'methylene dianiline	MbOCA
2,2'-Iminodi(ethylamine)	1,4,7-Tri-(aza)-heptane
2,3-Epoxypropyl isopropyl ether	Isopropyl glycidyl ether
2,4 DES	Sodium 2,4-dichlorophenoxyethyl sulphate
2,4,5-T	2,4,5-Trichlorophenoxy acetic acid
2,4-D	2,4-Dichlorophenoxyacetic acid
2-Aminoethanol	Ethanolamine
2-Aminopyridine	2-Pyridylamine
2-Butoxyethanol (EGBE) (CL)	Ethylene glycol monobutyl ether (RL)
2-Chloro-1,3-butadiene	beta-Chloroprene
2-Chloroacetophenone	Phenacyl chloride
2-Chloroethanol	Ethylene chlorohydrin
2-Cl-6-trichloromethyl pyridine	Nitrapyrin
2-Ethoxyethanol	Glycol monoethyl ether
2-Ethoxyethyl acetate CL	Ethylene glycol monomethyl ether acetat RL

2-Methoxyethanol	Ethylene glycol monomethyl ether
2-Methoxyethyl acetate	Ethylene glycol monomethyl ether acetate
4,4'-Diaminodiphenylmethane (DADPM)	4,4'-Methylenedianiline and MDA
6,6'Di-tert-butyl-4,4'thiodi-m-creso	4,4'-Thio bis(6-tert butyl-m-cresol)
Allyl Chloride	3-Chloropropene
Allyl glycidyl ether (AGE)	1-Allyl-2,3-epoxypropyl ether
alpha Methyl styrene	2-Phenylpropene
alpha Methyl styrene	2-Phenylpropene
Aminodimethylbenzene	Xylidene, mixed isomers
Antimony hydride	Stibine
Azinphos-methyl (ISO)	Guthion
Benzene-1,2,4-tricarboxylic acid 1,2 anhydride	Trimellitic anhydride
Benzoyl Peroxide	Dibenzoyl peroxide
Benzyl butyl phthalate	Butyl benzyl phthalate
Benzyl Chloride	alpha-Chlorotoluene
Bis (2,3-epoxypropyl) ether	Diglycidyl ether (DGE)

Bis-(2-ethylhexyl) phthalate	Di-sec-octyl phthalate
Bis-(2-ethylhexyl) phthalate	Di-(2-ethylhexyl) phthalate (dioctyl phthalate
Bromochloromethane	Chlorobromomethane
Bromoethane	Ethyl bromide
Bromoethylene	Vinyl bromide
Bromoform	Tribromomethane
Bromomethane	Methyl bromide - Skin
Bromomethane	Methyl bromide
Bromotriflouromethane	Triflourobromomethane
Butan-1-ol	n-Butyl Alcohol
Butan-2-ol	sec-Butyl Alcohol
Butan-2-one	Methyl ethyl ketone (MEK)
Calcium Carbonate (inhalable)	Limestone (inhalable)
Calcium Carbonate (inhalable)	Marble (inhalable)
Calcium Carbonate (respirable)	Limestone (respirable)
Calcium Carbonate (respirable)	Marble(respirable)

Carbon Tetrachloride	Tetrachloromethane
Carbonyl Chloride	Phosgene
Catechol	o-Dihydroxybenzene
Catechol (o-Dihydroxybenzene)	Pyrocatechol
Chlorinated biphenyls 42 % Cl	PCB's (42 % Cl)
Chlorinated biphenyls 54 % Cl	PCB's (54 % Cl)
Chlorodiflouromethane	Diflourochloromethane
Chloroethane	Ethyl chloride
Chloroform	Trichloromethane
Chloromethane	Methyl chloride
Chloropicrin	Trichloronitromethane
Cristobalite, respirable dust	Sillica,respirable crislatine
Cryofluorane (INN)	Dichlorotetraflouroethane
Cumene	Isopropyl benzene
Cyanogen	Oxalonitrile
Cyclonite (RDX)	Hexahydro-1,3,5-trinitro-1,3,5-triazine

Cyhexatin	Tricyclohexyl tin hydroxide
DDM	4,4'-Diaminodiphenylmethane (DADPM)
DDVP	Dichlorvos
Derris, commercial	Rotenone (commercial) (ISO)
Diacetone Alcohol	4-Hydroxy-4-methyl-pentan-2-one
Dialkyl 7-9 phthalate	Di-linear 79 phthalate
Dibrom 1,2-Dibromo-2,2-dichloroethyldimethyl P	Naled
Dichloromethane	Methylene chloride
Dichloroflouromethane	Flourodichloromethane
Dicyclopentadienyl iron	Ferrocene
Diethanolamine	2,2'-Iminodiethanol
Diethyl ether	Ether,Ethyl ether
Diethylene glycol	2,2'-Oxydiethanol
Diisobutyl ketone	2,6-Dimethylheptan-4-one
Diisopropyl ether	Isopropyl ether
Dimethoxymethane	Methylal

Dinitro-o-cresol	2-Methyl-4,6-dinitrophenol
Diphosphorus pentasulphide	Phosphorus pentasulphide
Disodium disulphite	Sodium metabisulphite
Disulphur dichloride	Sulphur monochloride
Divanadium pentoxide (inhalable dust and fume)	Vanadium pentoxide (inhalable)
Ethane-1,2-diol (particulate)	Ethylene glycol (particulate)
Ethanethiol	Ethyl mercaptan
Ethanol	Ethyl alcohol
Ethyl amyl ketone	5-Methyl heptan-3-one
Ethyl butyl ketone	Heptan-3-one
Ethyl silicate	Tetraethyl orthosilicate
Ethylene glycol dinitrate (EGDN)	Ethylene dinitrate
Ethylene oxide CL	Ethylene oxide RL
Fenchlorphos (ISO)	Ronnel
Flourotrichloromethane	Trichloroflouromethane
Glycerol trinitrate	Nitroglycerin

Hexan-2-one	Methyl n-butyl ketone
Hexone	Methyl isobutyl ketone (MIBK)
Hexylene glycol	2-Methylpentane-2,4-diol
Iodomethane	Methyl iodide
Iron pentacarbonyl	Pentacarbonyliron (as Fe)
Isoamyl alcohol	3-Methylbutan-1-ol, 2-Methylpropan-1-ol
Isobutyl methyl ketone	5-Methyl hexan-2-one
Isophorone	3,5,5-Trimethylcyclohex-2-enone
Manganese cyclopentadienyl tricarbonyl	Tricarbonyl (eta-cyclopentadienyl) manganese (as Mn)
Manganese tetroxide	Trimanganese tetraoxide
MbOCA (2,2 Dichloro-4,4 methelynedianiline)	4,4'-Methylene bis(2chloroaniline
MDI	4,4'-Methylene-diphenyl diisocyanate
m-Dihydroxybenzene	Resorcinol
Mercaptoacetic acid	Thioglycolic acid
Mesityl oxide	4-Methylpent-3-and-2-one
Methanethiol	Methyl mercaptan

Methanol	Methylal alcohol
Methyl isobutyl carbinol	4-Methylpentan-2-ol
Methyl isobutyl ketone (MIBK)	4-Methylpentan-2-one
Methyl parathion	Parathion-methyl (ISO)
Methyl silicate	Tetramethyl orthosilicate
Methylcyclopentadienyl manganese tricarbonyl	Tricarbonyl (methylcyclopentadienyl) manganese
Mevinphos (ISO	Phosdrin
n-Butyl Glycidyl Ether (BGE)	Butyl-2,3-epoxypropyl ether
Nickel carbonyl	Tetracarbonylnickel (as Ni)
Nitric oxide	Nitrogen monoxide
n-Methyl-n,2,4,6-tetranitro aniline	Tetryl
n-Propanol	Propan-1-ol
o-Acetyl Salicylic Acid (Aspirin)	Asprin
p-Benzoquinine	Quinone
p-Dihydroxybenzene	Hydroquinone
Phenylethylene	Styrene, monomer

Phenylethylene	Vinyl benzene
Picric acid	2,4,6-Trinitrophenol
Portland cement (inhalable)	Cement
Portland cement (respirable)	Cement
Propane-1,2-diol (particulates)	Propylene glycol (particulates)
Propane-1,2-diol (vapor and particulates)	Propylene glycol (vapor and particulates)
Propargyl alcohol	(Prop-2-yn-1-ol
Propylene glycol dinitrate	Propylene dinitrate
Silane	Silicon tetrahydride
Sulfotep	O,O,O',O'-Tetraethyl dithiopyrophosphate, TEDP
tert-Butanol	tert-Butyl Alcohol , 2-Methylpropan-2-ol
Toluene, 2,4 diisocyanate	4-Methyl-m-phenylene diisocyanate, TDI
Tri-o-Cresyl phosphate	Tri-o-tolyl phosphate
Vinyl chloride (CL)	Chloroethylene , Vinyl chloried (RL)
Vinylidene chloride	1,1-Dichloroethylene
y-HCH (ISO)	y-Hexachlorocyclohexane, Lindane

Table 2: Standard comparison list for geometric means method done for the developed countries

HAZARDOUS CHEMICAL SUBSTANCES	CAS NUMBERS
Dichloromethane (Methylene chloride)	75-09-2
2-Ethoxyethanol (Glycol monoethyl ether)	111-80-5
2-Ethoxyethyl acetate	111-15-9
Acetic acid	64-19-7
Acetone	67-64-1
Acrolein (Acrylaldehyde)	107-02-8
Allyl Alcohol	107-18-6
2-Aminoethanol (Ethanolamine)	141-43-5
Ammonia	7664-41-7
Aniline and homologues	62-53-3
Arsine	7784-42-1
Bis-(2-ethylhexyl) phthalate (Di-(2-ethylhexyl) phthalate (dioctyl phthalate)	117-81-7
Bromine	7726-95-6
Butan-1-ol (n-Butanol) (n-Butyl Alcohol)	71-36-3

Butan-2-ol (sec-Butyl Alcohol)	78-92-2
Butan-2-one (Methyl ethyl ketone)	78-93-3
Carbon Dioxide	124-38-9
Carbon Monoxide	630-08-0
Carbon Tetrachloride	56-23-5
Carbonyl Chloride (phosgene)	75-44-5
Chlorine	7782-50-5
Chlorobenzene	108-90-7
Chloroethane (Ethyl chloride)	75-00-3
Chloroform (Trichloromethane)	67-66-3
Chloromethane (Methyl chloride)	74-87-3
Chromium	7440-47-3
Cotton Dust - raw	N/A
Cychlohexane	110-82-7
Cyclohexanone	108-94-1
1,2-Dichlorobenzene (o)	95-50-1

1,4-Dichlorobenzene (p)	106-46-7
Dichloro diflouro methane	75-71-8
1,1-Dichloroethane (Ethylidene dichloride)	75-34-3
Diethylamine	109-89-7
Diethyl ether (Ether) (Ethyl ether)	60-29-7
N,N-Dimethyl acetamide	127-19-5
Dimethylamine	124-40-3
NN-Dimethylaniline	121-69-7
Dimethylformamide	68-12-2
1,4-Dioxane, tech. Grade	123-91-1
Divanadium pentoxide (inhalable dust and fume) (vanaduim pentoxide)	1314-62-1
Ethyl acetate	141-78-6
Ethylamine	75-04-7
Ethyl benzene	100-41-4
Formic Acid	64-18-6
n-Heptane	142-82-5

n-Hexane	110-54-3
Hexone	108-10-1
Hydrogen chloride	7647-01-0
Hydrogen flouride (as F)	7664-39-3
Hydrogen selenide (as Se)	7783-07-5
Hydrogen sulphide	7783-06-4
Isobutyl alcohol (2-methylpropan-1-ol) (Isobutanol)	78-83-1
Isopentyl acetate (pentyl acetates)(amyl acetates)	628-63-7; 626-38-0; 123-92-2; 625-16-1; 624-41-9
Maleic anhydride	108-31-6
Manganese dust and compounds	7439-96-5
Methanol (Methylal alcohol)	67-56-1
Methyl acetate	79-20-9
Methyl acrylate	96-33-3
Nitric acid	7697-37-2
Nitrobenzene	98-95-3
Orthophosphoric acid (phosphoric acid)	7664-38-2

Pentane	78-78-4; 109-66-0; 463-82-1
Pentyl acetate	628-63-7; 626-38-0; 123-92-2; 625-16-1; 624-41-9
Phenol	108-95-2
Phosphine (Phosporous trihydride)	7803-51-2
Phosphorus pentachloride	10026-13-8
Phosphorus trichloride	7719-12-2
Selenium and compounds - as Se	7782-49-2
Silver, soluble compounds - as Ag	7440-22-4
Sulphuric acid	7664-93-9
Tetrahydrofuran	109-99-9
Toluene	108-88-3
2,4,6-Trinitrotoluene (TNT)	118-96-7
Xylene, all and mixed isomers	1330-20-7

Chapter 4: Article 2

Comparison of South African occupational exposure limits for hazardous chemical substances with developing (BRICS) countries

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Abstract

Introduction: Over the years many differences in the setting and implementation of occupational exposure limits (OELs) have been reported.The aim of the study is to compare South African OELs to those of developing BRICS foundation countries (Brazil, Russia, India, China and South Africa) to acquire their status regarding OELs.

Methodology: The OELs established by the five developing countries that form the BRICS foundation were compared in the study. These five countries are all leading developing countries. The OELs were compared to the South African HCSR based on two aspects, selection of HCSs and the level at which the OELs for HCSs are set. The final database used for comparison consists of 710HCSs. Comparison was based on the number of HCSs that were listed by each country as a complete comparison list and a standard comparison list of the 39 HCSs. Comparison of the overall level at which the OELs are set was done by using the geometric means method. The geometric means methods for both the standard comparison list and the complete comparison list was analysed by a paired t-test and a Pearson correlation

Results: There are large variations in substance identification and selection between the BRICS countries so that there are many HCSs that are uniquely regulated. A total number of 326 HCSs are regulated by only one country and only 39 of all 710 HCSs was listed by all 4 countries (excluding Russia). The highest overlap in HCSs is between South African HCSR and Brazil. The average overall level of OELs differs substantially between countries; Russia having the lowest and Brazil having the highest overall limit when compared to the South African HCSR.

Discussion: Large differences exist in the selection of HCSs and the level at which the different BRICS countries set their OELs. Various factors are responsible for the large differences existing between countries. These factors include, variations in scientific reasoning, the risk acceptance of the negative impact that various HCSs might induce and the time lags that countries have between updates. Time lags between updated are one of the key factors in influencing the level of OELs. Further differences may be explained by the difference in consideration of socio-economical and practical feasibility of an OEL and the prominent industries in a country.

*Conclusion:*Large and unsystematic differences are found in the substance selection and the overall level of OELs between the BRICS countries. The unique HCS selection of the South African HCSR is slightly high when compared to the BRICS countries. South Africa, as part of the BRICS countries, has an overall higher level of OELs than other developing countries included, except for Brazil.

Key words: occupational exposure limits, comparison, developing (BRICS) countries,hazardous chemical substances, South Africa

4.1 Introduction

The phenomenon of using chemicals as part of processes involving processing and production is new. The occurrence of hazardous chemical substance (HCS) exposure in a work environment is therefore almost inevitable. Exposure to certain chemicals can affect a workers' health adversely. Occupational Exposure Limits (OELs) set by countries and other jurisdictions help to identify it is also meant to protect workers' health. Not all countries whoset these limits make use of the same standardized methods, there is therefore variation in how these limits are set and the concentration at which they are set (Schenk *et al*., 2008a). An OEL is an upper limit of the acceptable concentration of a hazardous substance in workplace air that most workers can be exposed to without harming their health or posing risks for adverse health effects (Rappaport and Kupper, 2008; Ding *et al*., 2011).OELs have been used since the early 1900's and most industrialised countries have a national authority issuing and implementing their own lists of OELs (Schenk *et al.,* 2008b; Paustenbach*et al*., 2011). Many countries across the world follow the lead of prominent trend setters such as: United Kingdom (UK) Health and Safety Executive (HSE), German Deutsche Forschungsgemeinschaft (DFG) and United States of America (USA) ACGIH (Shuker*et al*., 2007). Of which the ACGIH's TLVs is probably the most influential as many countries make use of these limits as a starting point and other countries merely adopt these values (Ding *et al*., 2011; Schenk and Johanson, 2011).

When exposure to airborne contaminants is concerned three types of OELs are commonly used: time-weighted average occupational exposure limits (TWA), short term exposure limits (STEL) and ceiling limits (CL). The main reason that OELs are set is primarily to protect a worker's health, and therefore the goal should be to keep exposure as low as reasonably possible. This is not always possible or practical in all the industries or countries and as a result there are numerous methods used to determine the concentration of a HCS that is safe to the majorityof the workers(Klonne, 2003). The different countries also use different designations to refer to their OELs these are listed in Table 1.

Different aspects play a role in the establishment of an OEL and consideration is not only based on health effects that a HCS may cause. The feasibility of OELs areoften determined by further considerations, such as socio-economic aspects and practicability (Ding *et al*., 2011; Schenk and Johanson, 2011). It is then these aspects that have a major influence on how OELs are set by different countries and gives rise to considerably differences in OELs set by different countries. Despite many attempts that have been made, harmonization of OELs and OEL setting processes has not yet been possible (Ding *et al*., 2011). With the rapid development of economic globalization there is a need for international harmonization for substance selection and setting of OELs among countries across the globe (Liang *et al*., 2006). Hansson and Ruden (2006) states that studies of OELs indicate large and unsystematic differences between decisions made and the values set for HCSswith similar adverse health effects. This further stresses the need for more standardisation.

By comparing South Africa's OELs for HCSswith other developing countries it can aid in determiningthe state of South Africa's OELs. The South African Department of Labour, under the guidance of the Minister of Labour, regulates the Hazardous Chemical Substances Regulations (HCSR) (South African Department of Labour, 1995; Brandys and Brandys, 2008) which are set for the general industries, whereas the OELs for the mining industries are set and implemented by the Department of Minerals and Resources and are stipulated in the Mine Health and Safety Act (MHSA) of 1996 and are referred to as the Mine Health and Safety Regulations (MHSR) (South African Department of Minerals and Resources, 1996; Brandys and Brandys, 2008).

In this paper we will systematically compare theHCSR of South Africa to four other developing countries: Brazil, Russia, India and China. All of these countries form part of a global initiative called the BRICS association. BRICS is an acronym that refers to the economies of the countries mentioned. All of these members are developing are newly industrialized countries that are known for their growing economies and influences (Ministry of Finance, Government of India, 2012). The five BRICS countries are distinguished from a host of other promising emerging markets by their demographic and economic potential to rank among the world's largest and most influential economies of the 21st century. Evaluating and comparing the lists of

OELs can help determine whether there is a significant difference in the limits set by these developing countries. Our aims are to identify and describe differences that exist between these lists of OELs of the developing countries with regards to two main variables: coverage of individual HCSslisted that refers to a comparison of the number of HCSs listed by each country and the overall level (concentration) of OELs set for the different HCSs.

Table 1: Characteristics of BRICS (developing) countries

Country	Standard Setting Organization	Designation of OEL	Legally Binding Status	Source of Influence	Date of publication
Brazil	Ministry of Labour Brazil	Tolerance Limits for chemical substances	Legally enforced by the Brazilian Ministry of Labour	ACGIH	1975
Russia	Russian Federation Department of Sanitary and Epidemiological Surveillance	Exposure Limits of harmful substances in the air of the working area	These levels are made legally enforceable to all by the Russian Ministry of Justice	Russia [a]	2008
India	The Ministry of Labour and Employment (Section 41F of Factories Act)	Permissible limits of Exposure of chemicals and toxic substances	Federally enforced by The Ministry of Labour and Employment	_[b] _[c]	2006/1956 [d]
China	The National Committee of Occupational Health Standards Setting (NCOHSS) Ministry of Health	Occupational exposure limits for hazardous agents in the workplace (GBZ)	Legally enforced by the Ministry of Labour is China	ACGIH Germany Russia JSOH	2007

[a]Russia has the list with the most number of substances regulated influenced by entirely toxicological data(Dobbie, J, personal communication, July 30; Russian Federation Department of Sanitary and Epidemiological Surveillance. 2007)
[b]Unknown or not available
[c]Multinational companies and large Indian companies that practice occupational hygiene in India use the ACGIH TLV's
[d] Uncertainty exists on the updated status of India's OELs, some sources state2006 and the official document refers to the Factory act of 1956

4.2 Methods

4.2.1 Lists of OELs

The different BRICScountries' lists of OELs were systematically collected. The lists were obtained by websites or through personal communication with the relevant parties and representatives. The language barrier was a confounding factor and most of these developing countries' lists were not freely available on the web. The regulatory agencies' lists of OELs that were obtained,are: Brazil, Russia, India and China. The Russian list of OELs was only available in Russian and the Brazilian in Portuguese. The following data was collected for each countryand is listed in Table 1: the standard setting organization, the designation of their OELs, legally binding status, whether legally enforceable, the source by which the country is most influenced if any, and finally the date ofpublication. This information was obtained for each of the developing countries and South Africa.

A CAS (Chemical Abstracts Service) number is a unique numerical combination assigned to each HCS that aids in the correct identification of a chemical substance. Previous studies done by Schenk *et al*. (2008a), Schenk and Johanson (2011) and Ding *et al*. (2011) on comparison of OELs between countries and jurisdictions only included HCSs that had a CAS number assigned to it. CAS numbers are absent in the South Africa's HCSR which complicated the comparison. A list of all possible synonyms and basic chemical structures was therefore used throughout the collection of different OELs to enable the correct identification and pairing of a specific HCS. The use of synonyms and chemical structures for identification ascertains that all chemicals and mixtures were included. In the South African lists of OELs there were synonyms (duplicates) of HCSs and they were removed and noted before commencing with the comparison. All the synonyms (duplicates) that were removed from the database are shown in Chapter 3 (Supplementary material).

4.2.2 Database used

A spreadsheet was used to systematicallycomplete the 8 hour TWA OELs of the different countries using South Africa as the standard or basic comparison list. The final database consisted of the OELs fromfive different countries. HCSs were listed based on their chemical names and the correct CAS number that was selected and listed accordinglyto enable correct pairing with HCSs. Many OELs for HCSsare listed in both ppm (parts per million) and mg/m^3 (milligrams per cubic meter). All of the OELs in this study were noted in mg/m^3 as this was the unit for which the least number of conversions were necessary and that occurred most in the different lists. Where necessary conversion were done from ppm to mg/m^3 using the following calculation as it was previously used in studies done to compare OELs (Schenk *et al*., 2008a; Ding *et al*., 2011; Schenk and Johanson, 2011):

Concentration (mg/m^3) = (Concentration ppm)(molecular weight)/24.45

The conversion equation is used at conditions that are standard at 25ºC and 1 atmospheric pressure for all HCSsthat were converted. For some of the HCSsconversionscould not be done. This is due to the fact that an exact molecular weight for the substance could not be obtained as the composition of the HCS varies (e.g. aliphatic hydrocarbons) and they were subsequently not included. For those HCSs that only have a short term exposure limit (STEL), the value was adjusted by conversion factors recommended by the ACGIH (Table 2) (Schenk *et al*., 2008a). Only a small number of conversions had to be made.

Table 2: Factors for recalculating an 8 hour TWA average from a STEL value as suggested by ACGIH (Hansson, 1997; Schenk *et al*., 2008a)

TWA (*ppm or mg/m^3*)	**C factor**
$X \leq 1$	3
$1 < X \leq 10$	2
$10 < X \leq 100$	1.5
$100 < X \leq 1000$	1.25
$1000 < X$	1

When more than one OEL was given for a HCS (e.g. inhalable and respirable, groups of chemicals and their isomers) both where included. The HCS for which the OEL was allocated for different working conditions, for example ozone, the designated OEL for a country or jurisdiction was given to all of the subdivisions. The final database used in this study contained 710HCSslisted according to their CAS number and OELs.

4.2.3 Coverage and selection of substances

The comparison was done by comparing the similarity between South Africa's lists of OELs in the HCSR with each of the individual developing countries. Not only the similarity of overlapping HCSs but also the number of HCSsuniquely regulated by each list was compared. The presence of HCSs on both lists were counted as overlapping, whereas the absence from either of the lists, amounted to the number of HCSs uniquely regulated by the country in question. The similarity in choice of substance selection between South Africa compared to the selection by the rest of the countries could be evaluated. As mentioned previously,every HCS listed was included even if there was more than one OEL for a HCS, such as soluble and insoluble forms. To furthermore compare coverage of HCSs we determined the number of countries which regulates each individual substance. This comparison was done by using only four of the five developing BRICS countries. Russia was discarded as there were only a limited number of 5 HCSs that corresponded with the other four countries used. This was done for each of the 710HCSsin thefinal database.

4.2.4 Statistical analysis

4.2.4.1 The geometric means method

Values of OELs in the list were compared statistically with the geometric means method. The method was first applied by Hansson (1997) and is used for the comparison of the overall level of complete lists of OELs (Schenk *et al*., 2008a; Ding *et al*., 2011). For comparison between two lists of OELs, it should refer only to those HCSsthat have OELs on both of the lists that are to be compared to one another(e.g. HCSR versus Brazil). The overlapping OELs yielded a longer, more comprehensive list for comparison. This is so that HCSs that are regulated by very few countries do not influence the average level that is calculated, such as the few HCSslisted by Russia. For comparison between the all countries only the HCS that were listed by all of the four countries involved were included in the standard comparison list. The final standard comparison list that was used comprised of39 HCSs. The geometric mean was then determined for these ratios. A quotient between the values on the different lists (complete comparison list of two countries and the standard comparison list) for each HCS was determined as the best indicator of the difference between two lists.

The importance for the use of geometric means rather than arithmetic means or median can be emphasized by the following; the list values when determined with arithmetic means will be perceived as having a higher value depending on which list is used as a denominator. To illustrate this, consider the following example: List *A* and *B* both assign OELs for three substances. List *A* allocates 20 ppm to substance I, 15 ppm to substance II and 10 ppm to substance III. On the other hand List *B* has set the OELs for the same substances at 200 ppm for substance I, 15 ppm for substance II and 1 ppm for substance III. The arithmetic means of ratios for *B/A* or*A/B* both equal 3.7, giving the impression that either *A* or *B* have set higher OELs irrespectively. In both these instances the geometric means of ratios equal 1 indicating that the overall level of the two lists does not differ (Schenk *et al*., 2008a; Ding *et al*., 2011). A geometric means lower than 1 indicates that the list being compared has a lower overall level of OELs, whereas a geometric mean value of above 1 indicates a higher overall level of OELs. By using the geometric mean the ratios are more representative irrespective of their denominator Schenk *et al*., 2008b; Ding *et al.*, 2011).

4.2.4.2 t-test for comparison of geometric means methods

Statistical analysis was done to determine whether there were significant differences between the standard comparison list and the complete comparison list used for the geometric means methods. This was done by conducting a paired t-test for the geometric means of the standard comparison list and the complete comparison list. Further, a Pearson correlation was also used to analyse the data in order to establish whether there is a statistical significant agreement between the standard and complete comparison lists. A p-value of smaller than 0.05 is considered to be significant.

4.3 Results

4.3.1 Comparison of OEL coverage

In the South African HCSR there were 155 HCSs with synonym names(duplicates). These were removed from the list before the comparison on the coverage of HCSs was done.

Coverage of individual HCS by each of the countries isillustrated in Figure 1. The number of HCSs listed by both South Africa and the developing country in question is shown along with substance coverage by each individually. Indicating the number of uniquely regulated OELs for each when compared to South Africa. An overall low correspondence of HCSs is seen for all of the countries. Brazil has the highest number of overlappingHCSs with only 120 HCSs that correspond with South Africa. With the least number of overlaps (5) occurring between South Africa and Russia. The HCSslisted only by South Africa have a prevailingoccurrence in the results with the most HCSs regulated and listed only by South African HCSR. Russia and China both have large numbers of HCSsthat are uniquely regulated and not listed by the South African HCSR.

Each of the 710 HCSs was evaluated against the number of developing countries that list the specific substance in question. The results are represented in Figure 2. The highest number of HCSs is listed by only one of the developing countries accounting for 46% or 327 of the total number of HCSs. The number of HCSs decreases dramatically as more countries' listings are added. Only 6% or 39 HCSs of all HCSs are listed by Brazil, India, China and South Africa.

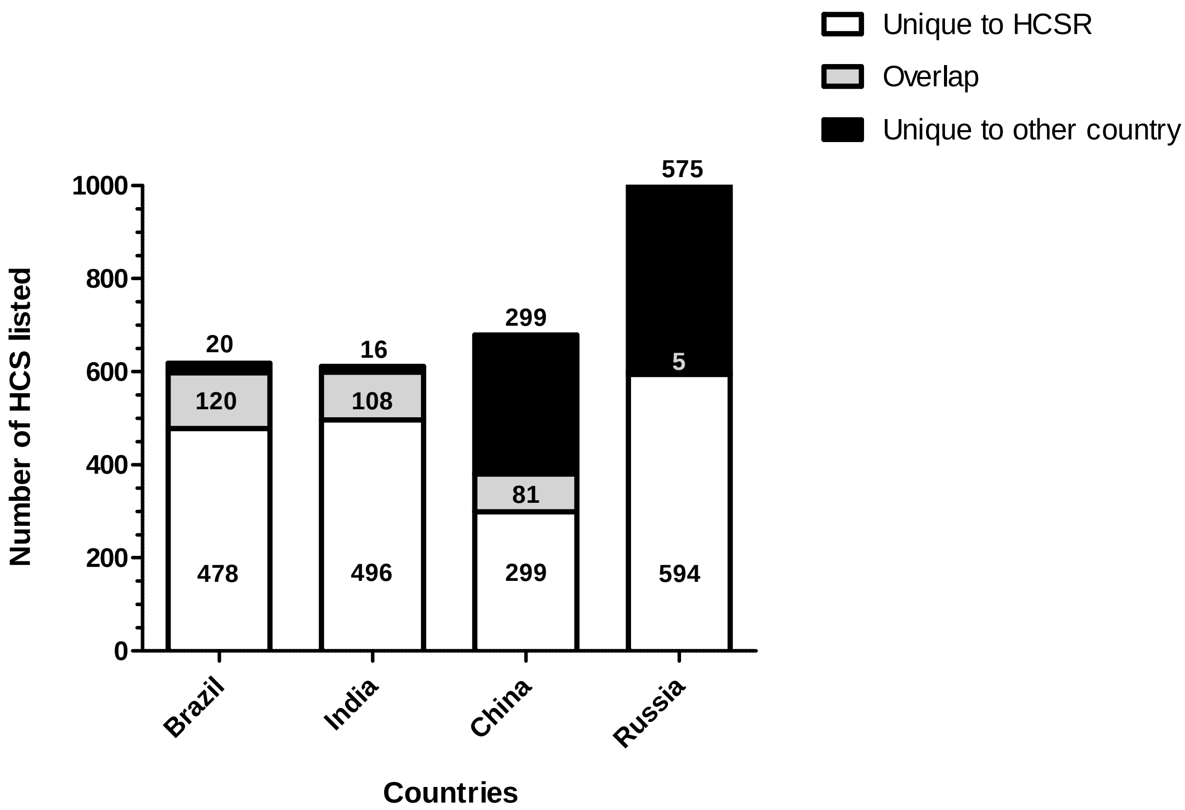

Figure 1: Coverage of HCSs listed by the different developing countries involvedcompared to the South African HCSR. The figure indicates both similarity and inconsistency in substance selection of the countries. The numbers of overlapping HCSs are indicated in descending order.

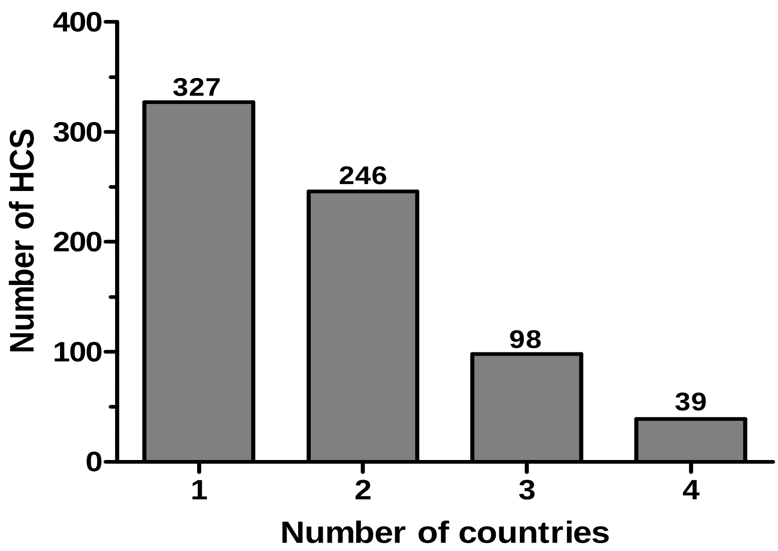

Figure 2: Number of HCSs and the number of developing countries that have included each of the HCS contained in the database of 710 HCSs.

4.3.2 Levels of occupational exposure limits

Table 3 contains the geometric means of ratios calculated for both the standard comparisonlist (39 HCSs) and the complete comparison lists of overlapping HCSs between South Africa and the various countries. Comparison of both lists areused to indicate the overall level of a country's OELs measured in relation to South African list of OELs. The geometric means method is used to compare the overall levels of OELs from different countries and jurisdictions relative to the HCSR of South Africa. All of the geometric means of ratios are smaller than 1, except for the complete list comparison for Brazil having a geometric means of 1.139. Figure 3A illustrates the geometric means of ratios for the standard comparison list: ratios are represented in ascending order with Brazil having the highest geometric means of ratios. China has the lowest geometric mean followed by India. Furthermore, the results for the complete comparison list based on the higher number of overlappingHCSs are represented in Figure 3B. Here Russia has the lowest value of geometric mean but Brazil still has the highest geometric means of ratios value.

Table 3: Geometric means of ratios of the comparison between South Africa and the developing countries based on both the standard comparison and the complete list of overlapping substances.

Country	Geometric means (standard)[a]	Geometric means[b]	No. of Substances [c]
Brazil	0.858	1.139	119
China	0.511	0.616	256
India	0.817	0.935	106
Russia	- [d]	0.266	5

[a] Geometric means of ratios based on the standard comparison list (39 substances listed by all 4 countries).
[b] Geometric means of ratios based on all the overlapping substances that were present between lists (HCSR versus other developing country)
[c] Number of substances that the second geometric means of ratio is based on (overlappingsubstances between South Africa and the various countries)
[d]The Russian list of OELs werenot included in the standard comparison list.

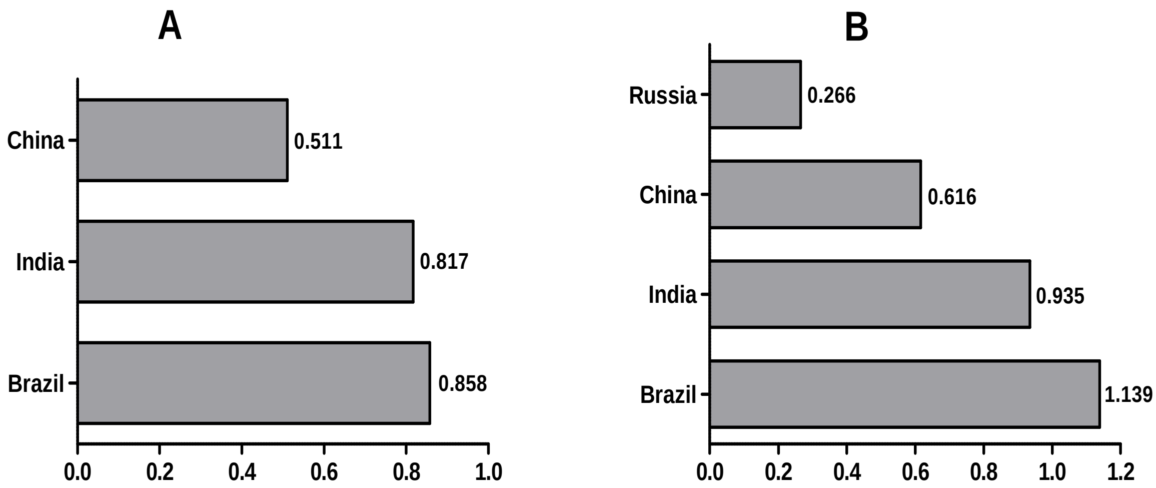

Figure 3: **(A)**The geometric means of ratios based on the standard comparison list compiled from the 39HCSs present in all 4developing countries excluding Russia. **(B)**The geometric means of ratios are based on all of the overlapping HCSs between HCSR and the various other countries. The geometric means of ratios are listed in ascending order in both figures.

4.3.3 Differences in lists used for comparison by geometric means methods

To determine whether there were significant differences between the geometric means methods for the standard comparison list used and the completecomparison lists of overlapping HCSs, a pairedt-test was performed. The shorter list of 39HCSs' geometric means of ratios was compared to the geometric means of ratios of the complete list.

A p-value of 0.421 indicates that there are no statistically significant differencesbetween the two lists. A Pearson correlation does, however, indicate that there is a strong significant correlation between these two lists(r=0.959 and p=0.018). Although the results from the geometric means of ratios may imply that the number of HCSs strongly influences the geometric means, the differences between the standard and complete lists are evidently small.

4.4 Discussion

South African OELs as contained in the HCSR were compared to those of the developing BRICS countries. Both the number of HCSs and the overall OEL levels were compared using South Africa HCSR as the base of all comparisons done. The results of this study show how South Africa compares to other developing. Comparison was based on our final database of 710 HCSs contributed by the various developing countries.

The large differences that exist in substance identification, selection and recognition are confirmed by the findings of this study. This is unique in the sense that comparison was done for countries that are all in approximately the same developing level. The inconsistencies that exist between these countries are pointed out bythe number of HCSs that are only regulated by one country; the highest number of HCSsare regulated uniquely by only one of the countries (46%). Only a few HCSs are regulated by all of the countries in this study, the 39 overlapping HCSs between South Africa, Brazil, India and China. Only five of the OELs of Russia corresponded with South Africa and therefore Russia was not included in the standard comparison list. Furthermore there were many HCSs regulated exclusively by South Africa when compared to the other developing countries. Russia and China are the two countries that have the highest number of uniquely regulated OELs when compared to South Africa. Data presented here confirms a large difference in substance selection between developing countries.

Different countries make use of different types of data and methods for setting OELs. As one would expect, there are large and unsystematic differences between the OELs, of the different countries (Schenk *et al.*, 2008a; Ding *et al*., 2011; Schenk and Johanson, 2011). Among the several studies done on the comparison of OELs South Africa has not yet been included.Various reasons are proposed for the existence of these differences including: scientific reasons, economic reasons, time lags between updates and the difference in the risk acceptance (Ding *et al*., 2011).The difference in predominant industries and exposure conditions among the developing countries are also important factors. The industrial structure of a country will make provision for the HCS that are most prevalent and harmful (Ding *et al*., 2011).

Time lags between updates can strongly influence OELs which can be a possible explanation for the variations that exist especially between developing countries as most of the countries have not recently updated their list of OELs (Schenk and Johanson, 2011). China and Russia have more recently updated lists of OELs compared to the other countries and this can be a possible explanation for the high number of unique selection of HCSs. Variations can also be explained by the difference in considerations of economic, technological and other factors. The study does not include the evaluation of the processes used by each country and thus no conclusion can be made on the factors that had an influence on the identification and selection of HCSs (Schenk *et al*., 2008a). Evaluation of the different countries' documentations containing this information was not possible due to the lack of transparency, non-accessibility and the language.

The geometric means of ratios for all except Brazil have a value below 1indicating that all of the countries have a lower overall OEL level than that of South Africa. Brazil has the highest overall level of OELs when comparison is done by complete comparison list. The current high level of Brazil's OELs can possibly be due to the large time lag since the last update in 1975 (Brandys and Brandys, 2008). India has the second highest overall level of OELs when compared with complete comparison list; here time lags may also be of key importance as they have only 116 HCSsthat were last updated in 1956, however uncertainty does exist about the date the OELs were last updated. China and Russia both have the lowest overall levels of OELs compared to South Africa and both where recently updated (2007/2008).The South African HCSR were published in 1995 and only a few minor updates have been made since (South African Department of Labour, 1995). As noted earlier, OELs seem to decrease as they are revised, thus this can be a possible explanation for the high level of these limits (Ding *et al.*, 2011). The levels of OELs can also be strongly influenced by the type of industries found in the various developing countries. The study of the level of OELs does not allow any conclusions to be made on the process or the actual working conditions (Schenk and Johnson, 2011). Our results from the comparison by geometric means of ratios for both the standard comparison list and the complete comparison list of overlapping HCSs concluded that there was no significant difference in the geometric means found by these two lists. Rather than a difference, a strong significant correlation was found between the lists usedhighlighting the significant use of such a standard comparison list containing HCSs listed by all of the countries.

4.5 Conclusion

The results of our study indicates the large and unsystematic setting of OELs among countries and further underlines the difference within the BRICS countries, even though they all are leading developing countries. A more in-depth investigation into the processes used by these different countries may give a more detailed description of why these large variations do exist (Schenk *et a*l., 2008b). Large differences exist in the selection of HCSs between countries. There may also be controversy in the science leading to different conclusions being made regarding various HCSs (Schenk *et al*., 2008a). The OELs as contained in the HCSR has an overall higher level of OELs compared to developing countries and jurisdictions. This may indicate that South African OELs in HCSR are inadequate to some extent to control exposure and protecting the South African workforce from adverse health effects resulting from HCSs exposure.

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4.6 Suplemental material

Table 1: Standard comparisonlist usd for the geomentric means method for developing countries (BRICS countries)

HAZARDOUS CHEMICAL SUBSTANCE	**CAS-NUMBERS**
Carbon Disulphide	75-15-0
2-Methoxyethanol (Ethylene glycol monomethyl ether)	109-86-4
Acetaldehyde	75-07-0
Acetone	67-64-1
Acetonitrile	75-05-8
Ammonia	7664-41-7
Aniline and homologues	62-53-3
Bromine	7726-95-6
Butan-1-ol (n-Butanol) (n-Butyl Alcohol)	71-36-3
Butan-2-one (Methyl ethyl ketone)	78-93-3
Carbon Monoxide	630-08-0
Carbon Tetrachloride	56-23-5
Carbonyl Chloride (phosgene)	75-44-5

Chlorine	7782-50-5
Chlorobenzene	108-90-7
Chloroform (Trichloromethane)	67-66-3
Cyanogen (Oxalonitrile)	460-19-5
Ethyl acetate	141-78-6
Ethylamine	75-04-7
Formic Acid	64-18-6
Hydrazine	302-01-2
Hydrogen chloride	7647-01-0
Hydrogen sulphide	7783-06-4
Mercury all other forms - as Hg	7439-97-6
Nickel carbonyl (Tetracarbonylnickel)	13463-39-3
Nitric oxide (Nitrogen monoxide)	10102-43-9
Nitrogen dioxide	10102-44-0
Orthophosphoric acid (phosphoric acid)	7664-38-2
Ozone (Heavy work	10028-15-6

Ozone (Moderate work)	10028-15-6
Ozone (Light work)	10028-15-6
Ozone (liht moderate or heavy work) (+< 2hours)	10028-15-6
Phenol	108-95-2
Phosphine (Phosporoustrihydride)	7803-51-2
Pyridine	110-86-1
Sulphur dioxide	7446-09-5
Toluene	108-88-3
Xylene, all and mixed isomers	1330-20-7

Chapter 5: Concluding chapter

In this chapter, conclusions will be made with reference to the aims, objectives and hypotheses of this study. Recommendations relating to the OELs of the South African HCSR will be given in an attempt to improve these OELs. The limitations of the study and the possibility of future studies will also be discussed.

5.1 Conclusions

The main aim of this study was to comparatively analyse the OELs in the South African HCSR with that of MHSR, developed countries and other developing (BRICS) countries to establish how South African OELs differs from other countries.

Coverage and selection of HCSs between the different developing and developed countries and jurisdictions in the study was inconsistent and dissimilar. This confirmed the large and unsystematic differences in the selection of HCSs that are chosen to be regulated by each country. There were more overlaps between the substance selections of South African HCSR with developed countries than those of developing countries. When compared to the BRICS countries there were fewer overlapping HCSs and South Africa had the highest number of unique substance coverage. Most of the HCSs that were part of the database for both the developed and developing countries were regulated by only one of the various countries involved. Indicating the difference in substance selection regardless of the developmental status of the country and concluding that other factors may need to be taken into consideration when comparing substance coverage. The time lags between updates are one of the most prominent factors and as a pressing issue (Hansson, 1997; Schenk and Johnson, 2010), it underlines the long time lag since South Africa HCSR has last updated their list of OELs. Countries such as India and Brazil had very few HCSs that are uniquely regulated by them and both these lists were updated in the 1900’s (in 1956 and 1975 respectively). Difference in the predominant industries that are present in a country is another noteworthy factor influencing the coverage of HCSs between countries (Ding *et al*., 2011). The hypothesis relating to the considerable differences in the number of HCSs that are listed in South African HCSR, in comparison with other countries, is accepted based on the findings of this study.

The OELs as listed in the HCSR have an overall higher level than the majority of developed and developing countries with exception to OSHA and Brazil. Compared to the rest of the countries, the study indicated geometric means of ratios all below 1 pointing out the overall higher level of OELs of South Africa. The strong influence of ACGIH is justified by the lowest overall level of OELs and will therefore in all probability continue to be an important influence (Brandys and Brandys, 2008). Compared to South African HCSR the developed countries had significantly lower overall levels of OELs than the developing countries. Even when compared to the BRICS countries that are classified as having the same developmental status and potential for growth, South Africa still has a higher overall level of OELs. Strong agreements between South African HCSR and MHSR were found indicating national similarity. The MHSR was however more recently updated and had slightly lower overall levels of OELs (Department of Minerals and Resources, 1996). The hypothesis that the level at which OELs in the HCSR are set differs significantly from the values set by other developed and developing countries, is accepted.

Reflecting on the results that were yielded by the comparison of South African HCSR with both developed and other developing countries it is possible to make an indirect conclusion regarding how adequate the OELs listed in the HCSR are. Both the inconsistent selection and coverage of HCSs and the overall higher level indicates that the OELs for South Africa listed in the HCSR can be classified, to some extent, as inadequate to control exposure and to protect workers against the harmful effects of HCS exposure.

5.2 Recommendations

OELs are an essential part of the occupational health and safety practices used to control exposure to HCSs and to protect the health of workers. Control of exposure to HCSs is a South African legislative requirement and OELs may be a helpful tool for ensuring control and management of HCS exposure. The Department of Labour, as custodians of the Occupational Health and Safety Act (Act 85 of 1993) and HCSR, has indicated that they are in the process of updating the HCSR. The following recommendations are made:

Recommendation 1: Developing and implementing a strategy that ensures immediate and periodic revision processes for the OELs listed in the HCSR. Ensuring that OELs are frequently revised and updated to provide the adequate protection to South African workers. ACGIH revises their OELs systematically annually and Sweden on a 2 year basis, thus it is recommended that the South African OELs in HCSR be revised and updated at least every 5 years, since the capacity in doing so may intend to do it more frequently.

Recommendation 2: Draw up supporting documentation providing additional information on OELs and the OEL setting processes. The documentation must accompany the OELs and should be easily accessible.

Recommendation 3: Adoption of the ACGIH's TLVs is recommended as they play a universal role in setting health based OELs. It may be possible that not all of the TLVs can be merely adopted this is due to the differences in predominant industries between South Africa and the ACGIH. If adoption of all TLVs are not possible it is therefore recommended that South Africa revise and set their own criteria for selected HCSs.

Recommendation 4: Revision of the current HCSR regarding the synonyms (duplicates) within the Regulations and the use of a single complete list of OELs rather than OEL-RL and OEL-CL is recommended. These synonyms need to be removed especially the substances listed as a OEL-RL and then as a duplicate in the OEL-CL list (e.g. 1,2 –Dibromoethane versus Ethylene bromide, Vinyl chloride and Dichloromethane versus Methylene chloride).

Recommendation 5: Assigning CAS numbers to the HCSs that are listed in the HCSR as this is a more comprehensive and accurate way of identifying the correct HCS in question. By implementing this recommendation it will automatically eradicate the duplicates among the HCSs (synonyms in HCSs).

Recommendation 6: It is recommended that provision is made for different subdivisions/isomers of chemicals where applicable. To illustrate such an example: take manganese listed as manganese and its compounds, more specifically it can be divided into manganese (II) phosphate, manganese (II) chloride, manganese metal, manganese (II) oxide, manganese (IV) oxide and manganese (II) sulphide.

Recommendation 7: Specifying the different working conditions where exposure may occur and the appropriate OELs. For example specifying concentrations of ozone when light-, moderate- and heavy work is being performed.

5.3 Limitations of the study

In retrospect, there were a number of limitations that occurred whilst conducting the study.

- The absence of CAS numbers in the South African HCSR complicated comparison between different countries.

- The different countries and jurisdictions lists were not readily available and therefore this was a limiting factor relating to the number of countries and jurisdictions that the comparisons were based on.

- The language barrier made accessing and the interpretation of different countries lists difficult as there are lists of OELs that are not available in English.

5.4 Future studies

To make conclusions on the adequacy of OELs and their effectiveness, the study can be repeated with more in-depth investigation taking the following into consideration:

- Evaluation of the supporting documentation of the individual countries and jurisdiction providing more information on the processes and criteria used for setting their OELs. A rigorous investigation into the predominant industries within a country or jurisdiction is proposed as this may be a possible source of differences.

- Carcinogen classification of different HCSs was not assessed in this study. Comparison of identification and selection of carcinogens can enable additional conclusions to be made from the list of OELs compared.

- Finally, STEL values give an idea of the acute toxicity of a HCS. Thus it could be of value to repeat the study and evaluate the STEL and TWA values independently yielding a more representative assessment of the levels of OELs set by different countries and jurisdictions.

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Chapter 6: Appendices

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To whom it may concern

I, Kalienka Marx (21276056), declare that I have done the proof reading as well as the grammar editing for Ms. L. Viljoen (21121486) for her mini dissertation entitled **Comparison of South African occupational exposure limits for hazardous chemical substances with those of other countries**.

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To whom it may concern

PROOFREAD OF THE MASTERS DEGREE DISSERTATION (FACULTY OF SCIENCE)

Hereby I, Martin van der Linde, declare that I have proofread the above mentioned MA Dissertation.

I have obtained my degree in linguistics and therefore am authorized, qualified and completely able to do editing of manuscripts.

Regards

M.I. VAN DER LINDE
LINGUIST