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01. Length

Articles should be between 3000 and 6000 words or 15-20 typewritten pages. An abstract of not more than 250 words should be supplied.

02. Organization

The general organization of research papers should be as follows; the nature and scope of the study should be stated first, then the theoretical framework, followed by methodology including methods, materials, tools/ equipment used, and procedures; findings, discussion and conclusion. Appendices may be used to amplify details where necessary.

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If quotations are used, they should be included in the text within inverted commas ("…") and should be appropriately cited with page numbers.

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Give the **last name** of each author, use a comma after each last name and after each set of initials except the final one(s). Use an ampersand **(&)** rather than the word **'and'**.

For books

Calder, J. (1994). *Programme Evaluation and Quality,* Open and Distance Learning Series. London: Kogan page.

For articles

Weerasinghe, B (1999). Project for Enhancement of Distance Education of the Open and Distance Education of the Open University of Sri Lanka with British Overseas Development Assistance – An Overview. OUSL Journal, 2, 3-25.

For chapters within books:

Campbell, C. (1990). Writing with other's words: using background reading text in academic compositions. B. Kroll (Ed.), Second Language Writing (pp.211-230). Cambridge, England; Cambridge University Press.

For Conference Papers:

Gunawardena, C., Menon, M., & Naidu, S. (2004). The making of teacher educator, Paper presented at the 3rd Pan-Commonwealth Forum, Dunedin, New Zealand, June 4-9.

For Online Documents:

Collis, B. (1998). Implementing innovative teaching across the faculty *via* the www. Paper for the conference "SITE 98", March 1998, Washington, DC. Available Online at: http://education2.edte.utwente.nl/teletophomepage.nsf/papersUKViewform?readform (accessed 19 January 2006).

04. Tables and Figures

Tables and Figures should be numbered with Arabic numerals in the order in which they are cited in the text. Each table/figure should be titled. Titled should be brief and precise.

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Editorial

This is the seventh issue of the OUSL Journal, the Journal of the Open University of Sri Lanka. It provides OUSL academics and others a platform to publish research and review articles on Distance Education and other discipline based academic work conducted locally and internationally. The articles published in this issue cover research on ODL, Science and Engineering conducted by mainly OUSL academics. This gives a good opportunity for our readers to know some of the research conducted at OUSL and to engage in fruitful discussions and future collaborations.

The first research paper by De Silva and Devendra investigates the needs and expectations of undergraduate students who are following the course unit "English for General Academic Purposes" (EGAP) at The Open University of Sri Lanka. This course is offered to almost all students who need to enhance their core academic English language skills. The findings suggest that students have a wide range of needs, for example, academic, occupational and social needs, which they hope to fulfill by following the EGAP course. This diversity of needs warrant future development and delivery of the EGAP course, taking into consideration the needs of students who are involved in learning a variety of disciplines. Thus, the academic staff in the Department of Language Studies should re-examine the resources and opportunities that are currently available at OUSL (Multimedia, Moodle, OER and Video Conferencing).

Gunawardena and De Silva in their article discuss the impact of temperature and water stress on growth and yield parameters of chilli. Results suggest that the temperature stress affects the plant height, branches, canopy diameter, fruit weight, fruit diameter and number of fruits per plant. Reduction in harvest due to temperature stress can be overcome by watering during growing period.

Estimation of groundwater recharge, particularly in dry regions, is important for the management of scare water resources. Recharge rate depends on factors such as precipitation, temperature and evapotranspiration. C. S. De Silva, in a theoretical paper, simulates the potential groundwater recharge in the Jaffna Peninsula of Sri Lanka using HYDRUS-1D model. It was pointed out that the simulated potential groundwater recharge in this area is about 42 cm.

Nupearachchi and Perera, in their paper, study dielectric properties of composite films made from tin(IV) oxide and magnesium oxide. 10% of MgO in the SnO_2/MgO composite showed a high impedance which is in two orders of magnitude higher than pure MgO, probably due to the confinement of electrons in quantum well structure formed by a layer of MgO around SnO_2 particles. These composite films may find applications in devices such as capacitors and thin film transistors.

The research paper titled "overhead pedestrian crossings: economic evaluation through vehicle operating cost and travel time savings" presents a study carried out at the main entrance to the Sri Lanka Institute of Information Technology at Malabe to minimize the disturbance of traffic flow along the Malabe-Kaduwela road. Introduction of an overhead pedestrians' crossing at this location is proposed to minimize the vehicle-pedestrian conflict and to create a uniform traffic flow along the road.

The review by Shyama Weerakoon on "introducing herbicide resistant crops (HRCs) to Sri Lanka" deals with the pros and cons of cultivating HRCs, although, in some developed countries, a limited number of HRCs have been commercialized. Breeding of HRCs is proposed as a measure to relieve the constraints associated with herbicides. Farmers were benefited by cultivating HRCs, though there are many concerns about health risks and environmental impacts. A comprehensive study is vital to fully assess the potential benefits and adverse consequences before introducing HRCs to Sri Lanka.

In addition, this issue includes the Convocation Address-2014 made by Professor Som Naidu titled "Looking Back Looking Forward: The Invention and Reinvention of Distance Education" which reflects on the field of distance education, its journey since 1980 and its role in the future.

We welcome your suggestions for further improvement of this journal. We are looking forward to publishing your current research findings in our next issue.

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Responding to English Language Needs of Undergraduates: Challenges and Constraints

A study of the needs and expectations of students in the English for General Academic Purposes (EGAP) programme at the OUSL

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Abstract

This article presents the findings of a study which investigated the needs and expectations of a group of students registered for an undergraduate degree programme offered in the medium of English which is the students' second language (L2), at the Open University of Sri Lanka. The study was conducted at the beginning of the English for General Academic Purposes (EGAP) Course which is offered to these undergraduates to enhance their core academic English language skills. The views of the teachers of main subject disciplines about the importance of English for successful functioning in their respective academic disciplines were also investigated. The challenges, constraints and possibilities in meeting the needs and expectations of these stakeholders are also discussed.

Keywords: EAP, EGAP, Stakeholder needs, expectations

Background

Learner-centred approaches to curriculum development have been a major trend in language teaching in the past two decades. The main characteristic of a learner-centred approach is the importance given to learners' needs and their expectations in the curriculum design process (Dudley-Evans & St. John, 1998; Hutchinson & Waters, 1987). An analysis of students' needs and interests may be useful in identifying or revising the goals and objectives of a course, deciding on methodology, and determining means of assessment and evaluation (Nunan, 2004).

According to Widdowson (1983), English for Specific Purposes can be categorized according to the specificity of the aims of the course. He proposes that the designers need to "look for ways of defining the aims of our students in communicative terms by

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devising a means of analysis which preserves the essential features of language use" (Widdowson, 1983, p.6). Based on Widdowson's view, Bruce (2005) suggests the need for a discourse-focused approach to General English for Academic Purposes syllabus and course design which "relates to cognitive genres; is not discipline-specific; and uses a top-down approach in order to develop capacity as well as competence (enabling learners to reapply discourse knowledge in varying situations and forms)" (p.240). The course design is thus informed by a variety of data which includes the intentions, needs and plans of principal stakeholders of the course. Bruce (2003, cited in Bruce, 2005) proposes four rhetorical types of cognitive genres in academic discourse and one of the needs specified by Bruce is to 'identify discourse categories that are not discipline specific (cognitive rather than social genres) for use in the instruction of groups of students preparing for studies in a variety of disciplines' (p.244).

Different approaches to EAP have been debated in the research literature. Some researchers (Pennycook, 1998) argue that EAP approaches are based on dominant western academic cultures with zero tolerance of other cultures and traditions. The value of a socio-cultural dimension to academic literacy is highlighted by some researchers (Hyland, 2000; Swales, 1990) and according to them, in the area of academic writing, communicative purposes are shared and communicative conventions are sanctioned by specific discourse communities. Some others believe that academic language is embedded within disciplinary cultures (Freedman, 1999; Hansen, 2000) and they question the generalizability of an academic discourse across various disciplines in a university. Samuda (2001) criticizes various approaches used in EAP teaching and stresses the importance of learner needs in curricular design. As Fox (2009) points out, EAP curricular design and instruction should be informed by diagnostic assessment of 'individual student needs and strengths' which are essential in supporting efficient and effective language development and 'works well in tandem with traditional EAP approaches' (p.38). Fox also comments on the value of a diagnostic approach in identifying the factors that affect students' academic success other than their language proficiency (*i.e.* motivation).

As Benesch (1996) points out, 'needs analysis is a subjective process' which depends on the 'analyst's ideology' whereas critical needs analysis attempts to identify areas where 'greater equality might be achieved' (p.736) by giving more power to lower levels in

the hierarchical order *i.e.* students. Benesch (2009) discussing the demands of globalization and their impact on EAP students, teachers, and curricula, claim that the critical EAP does not encourage decontextualised topics which may create problems for teachers and students: 'Instead, grounded in the theoretical construct of situatedness, critical EAP finds its subjects in the daily and academic lives of students, presenting those topics respectfully to promote deep emotional connection and intellectual engagement' (p. 84-85).

Belcher (2006) reviews the current debates on needs analysis with particular relevance to English for Specific Purposes (ESP) and claims that while some critical pedagogists (*e.g.* Canagarajah, 2002; Philipson, 1992) view addressing learner needs in ESP as supporting expansion of English to fields of education, employment, research and technology and strengthening of its position in the non-English dominant world, others with EAP experience (e.g. Benesch, 2001; Pennycook, 1997) 'have constructed conceptual bridges between critical and pragmatically needs-based perspectives on pedagogy' (p. 143). Benesch (2001) emphasizes the need to redefine needs analysis to include 'rights analysis' which is a more democratic approach that takes into consideration target situation needs as well. According to Benesch, language curriculum design should be informed by 'a framework for understanding and responding to power relations' (p. 108) which empowers students with confidence to challenge undesirable situations and this is possible only if instructors attempt to 'discover what is possible, desirable, and beneficial at a certain moment with a particular group of students' (p.109).

Alexander, Argent and Spencer (2008), discussing the expectations of non-native speaker students in the UK, point out the danger in stereotyping those students since each individual student has his/her own individual expectations and needs. They examine the distinctive features of EAP in relation to context, people and teaching learning content and claim that understanding of these features is useful in identifying students' needs and determining how to meet those needs. EAP teachers, according to them, have a crucial role to play in 'relating to academic communities as language experts' which may benefit EAP students (p.15).

In distance learning contexts, the learners' ideas about their needs and preferences and their perceptions of the learning context have been considered as key factors which determine their language

learning. According to White (2003), "distance language learning changes the teaching-learning relationship that students have been confronted with for much of their lives" and "they need to be supported in finding ways of effectively managing themselves and their learning experiences" (p. 98). In order to provide learners with necessary support, it is essential to have an understanding of their perceptions, needs, expectations and their plans for language learning.

Studies on Needs Analysis

A variety of studies have been conducted in diverse contexts which have explored the needs, expectations and perceptions of students in relation to courses that support EAP skills.

Dooey (2010) explored the experiences and perceptions of a group of international students studying in Australia using semi-structured interviews. The results revealed that students had problems in using academic language skills such as making formal presentations, engaging in group discussions, research skills, and referencing. In addition to these academic skills, students expressed their concern about the disparity of English proficiency levels among students, intercultural communication and even about having too many speakers of Chinese languages. According to Dooey, 'the most urgent need from the students' perspective was to improve their English language skills in the most efficient way possible, to enable them to cope with their assigned tasks' (p.187). They were very keen about developing their oral communication skills and were worried especially about the inability to contribute meaningfully in group discussions, and about the difficulties in articulating sophisticated ideas and abstract concepts in English.

Evans and Green's (2007) large scale survey of the EAP needs of Cantonese speaking students in Hong Kong revealed that students' difficulties related largely to the fields of academic writing (style, grammar and cohesion) and academic speaking (particularly grammar, fluency and pronunciation). Even though the study highlighted the need for further enhancement of vocabulary and grammar, the authors contend that this does not justify a return to remedial general English language course and that the best approach would be to further focus on existing EAP programmes to address identified needs. The researchers further note the practical constraints such as the limited number of

classroom hours per semester that impinge on accommodating a wide range of needs.

Chostelidou's (2010) study of the English language needs of accountancy students enrolled in a Tertiary Institute in Greece highlights the multiplicity of student needs that need to be considered in developing English language support courses. The study revealed that there was a requirement for a highly specific ESP course to fulfil their immediate needs. However students also wished to develop language skills to help them function as professionals in the accountancy business in the long term. Therefore both short term and long term needs are to be taken into account in this particular context. This issue of the complexity of needs is further highlighted by Chien and Hsu (2010) whose study indicated that students' basic English skills in the areas of listening, speaking, reading and writing need to be further developed before specific needs were addressed in the context of an ESP programme.

Exploring the needs of international students studying in the UK (specifically Chinese students), Edwards and Ran (2006) found that in addition to the emotional challenges they face in adjusting to life in the UK, these students have specific needs which are a result of their Confucian heritage. Those students whose English language proficiency is limited have to rely on their native speaker friends, supervisors or commercial services when doing their academic work. Edwards and Ran opine that the needs of these students are too complex to be dealt with in a support course for English and the universities need to address their specific needs with flexibility, rather than attempting to absorb them into the existing structures.

A needs analysis survey conducted by Chowdhury and Haider (2012) in an Asian context (Bangladesh) using 40 undergraduates and four EAP teachers found that the existing EAP courses have major drawbacks in meeting learners' expectations in using acquired skills for both academic and professional purposes. These students felt reading, writing and speaking skills are more important to them than listening. However, the teachers were of the view that the students are unable to see the relevance of the English course in their main course of study and they consider it as an obstacle which has to be removed. Chowdhury and Haider recommend improvement in current EAP material through

incorporation of materials relevant to core subjects and by giving more emphasis to productive skills *i.e.* writing and speaking.

Mazdayasna and Tahririan's (2008) study of the ESP needs of Iranian undergraduate medical sciences students showed that they believed that reading comprehension followed by listening, speaking and writing skills were important skills that needed to be addressed. This view was also supported by the subject specific instructors who also attached greater importance to these skills than the students. The study is also important in that it also indicated the constraints and obstacles that impinged on fulfilling these identified student needs. These included limitation of time, the number of students in class, the teaching methodology used and the perceived limitations of the English Language Instructors.

Fox, Cheng, Berman, Song and Myles (2006) stress the importance of taking into consideration 'the heterogeneity and 'positioning' of the population under investigation' when making generalizations and predictions about learner needs, academic performance and when making recommendations for language support programmes (p. 2). Investigating L2 undergraduates in three Canadian universities, they found that it is necessary to develop students' learning and social skills, their ability to make strategic choices regarding academic and social support that develops English and providing formal EAP or ESP instruction to support successful academic acculturation of these students.

English Language Teaching and Learning in Sri Lanka: Expectations and Perceptions

In an ethnographic study which investigated student motivation, attitudes and their subjectivities to learn English using lived experiences of Tamil EAP students in northern Sri Lanka, Canagarajah (2001) found that students expected the course to be grammar-oriented and they disliked skills or activity based teaching of English in the EAP classroom. Canagarajah noted a drastic fall in student attendance which he attributes to the irrelevance of material used for teaching.

Investigating the perceptions of university students on the role of English language proficiency in higher education, career choice and mobility, Ranasinghe and Ranasinghe (2012) found that the respondents believed knowledge of English is necessary to perform well in higher education and they considered it as 'a means for upward career mobility and better career prospects' (p.204). The impact of English on students' performance in main academic programmes was surveyed by Vidanapathirana (2009) with reference to the B.A. in Social Sciences Degree programme at OUSL and he found that there was a significant association between students' performance in English and their performance in main subjects in the Social Sciences. Vidanapathirana reports that 'the success rate (percentage of learners completing the programme) as well as the quality of success (learners securing good passes) are invariably linked to competence in the English language' (p. 70).

Another study (Perera, 2006) which used first year undergraduates in a Sri Lankan national university found that students 'have an overwhelming desire to learn English brought about by their perception of English as the direct link to future employment and success'(p.51). Perera found that fulfilling this need through a single level course was not feasible and describes an attempt to introduce a lower-level course to support the needs of low-proficiency students. As Ratwatte and Herath (2006) point out 'this is a good example of change in language education policy that needs to take place not only at national level but at institutional levels as well if we are to meet needs of different student populations and achieve the goal of teaching English' (p. ix). According to Perera (2006), limited contact hours allocated for English by the faculty administration is a huge constraint in addressing the needs of these students.

The performance in English of a group of doctors registered at the Postgraduate Institute of Medicine, University of Colombo, Sri Lanka who followed a training course for IELTS (International English Language Testing Service) was investigated by Raheem, Medawattegedara, and Miththapala (2007). The findings revealed that the trainees had not been able to reach the required standard in the skill of Writing for postgraduate training abroad even after receiving training for eight months. Raheem and Wijetunge (2009) report the findings of a recent study which investigated the undergraduate English Language Proficiency in the Sri Lankan University system using Test of English Proficiency (TEP)

specifically designed for this purpose. This test evaluated the proficiency in all four language skills: Reading, Writing, Listening and Speech. They used a systematic sample to include students from 12 universities, studying different disciplines i.e. Engineering, Science, Medicine, Social Sciences and Management/Accountancy. Raheem and Wijetunge (ibid) note that out of the four skills, the weakest performance was in the Writing skill.

How the views on English have changed over time and how opinions about English differ among different social groups in Sri Lanka were investigated in a study by Ratwatte (2012). She examined the opinions expressed in the written media (English) by English speaking authors and compared those with the opinions expressed by the 'masses (those who have an inadequate knowledge of English)' (p.181). The study revealed that there is agreement as well as mismatch between the opinions expressed by these two speech communities. The views held by the learners' society *i.e.* English is necessary for employment and tertiary education have an influence on the learners while 'the relevance of English for other spheres seems to be one largely held by the 'English-fluent' segment of society.' As Ratwatte (2012) points out, there is a resistance to learning 'when the learner cannot see the usefulness of a task or the relevance to his life' (p.200).

Previous studies on learner needs, as discussed above, have identified a wide variety of learner needs and how they vary in different contexts. While stressing the importance of taking into account the heterogeneity of the student population, the context, and individual learner needs in course design and delivery, they discuss the issues and constraints in addressing those in different contexts.

Previous studies on learner needs, as discussed above, have identified a wide variety of learner needs and how they vary in different contexts. While stressing the importance of taking into account the heterogeneity of the student population, the context, and individual learner needs in course design and delivery, they discuss the issues and constraints in addressing those in different contexts. Hence, it was considered important to carry out a study which would reveal the needs and expectations of main stakeholders of the English for General Academic Purposes Course at the Open University of Sri Lanka.

The present study attempted to answer the following research questions.

Research Questions

1. What are the needs and expectations of a group of students registered for an English for General Academic Purposes course at the Open University of Sri Lanka?

2. What English language skills do the lecturers in academic departments think are necessary for students' successful completion of the degree?

3. What are the challenges faced by EAP course designers when addressing stakeholder needs and expectations?

Methodology

The study used 100 essays written by 100 students registered for the English for General Academic Purposes course from the Faculty of Natural Sciences and a questionnaire to 26 lecturers from the Faculty of Natural Sciences as data collection instruments.

The present study explores the students' needs and expectations through a piece of writing (a timed essay) written by the students on a given topic prior to the beginning of their English course. The rubrics for the task guided the students to structure their essay on their needs to learn English, their expectations of the EGAP course and their plans to improve their English. Their performance in writing was evaluated separately by a set of marking examiners and the researchers were not involved in that process. The scripts were selected randomly for the research study later. A random sample of 100 essays was used in the study and the data were analysed both quantitatively and qualitatively. A Content Analysis of the essays was carried out by coding the data using a coding scheme which was designed using a sample of data. Content Analysis is considered as an unobtrusive method of data collection as it does not involve the researcher interacting with the people being studied. The essays did not contain the students' names. A sample of data was coded by both researchers

independently and the discrepancies in coding were removed after a discussion. The inter-coder reliability was above 0.9 for most of the categories. The presence of a particular category was counted as "1" (irrespective of the number of occurrences) while the absence of it was counted as "0".

Results and Discussion

Table 1. Descriptive Statistics for Types of Needs (Total)

	N	Min	Max	Sum	M (SD)
Academic Needs Total	100	0	6	219	2.19 (1.14)
Social Needs Total	100	0	3	96	0.96 (0.76)
Occupational Needs Total	100	0	3	71	0.71 (0.80)

As shown in Table 1, the needs that were mentioned in the informants' essays (N = 100) were identified and coded under three main categories, namely, Academic needs, Social needs and Occupational needs (mentioning of a particular type of need was counted only once irrespective of the frequency of occurrence) and descriptive statistics were calculated using SPSS 16.0. Out of the three kinds of needs, the highest mean was found for the need for using English for academic purposes. The need to use English for social purposes had the next highest mean while the need for English for occupational purposes had the lowest mean out of the three types.

Academic Needs

As shown in Table 2, the Academic Needs Total found in students' written texts was 219 and the highest mean was reported for Academic Needs with a narrow angle (required to fulfil immediate needs relating to study programme). Academic Needs with a wide angle and technological needs had the second highest mean. The mean for the need for the mastery of all four skills was the next highest. The results show a few instances where the informants mentioned the need of English to interact with peers and the staff. None of the students, however, reported that English is necessary to communicate with the academic institution.

Table 2. Descriptive Statistics for Academic Needs

	N	Min	Max	Sum	M(SD)
Academic Needs Wide	100	0	1	55	0.55(0.50)
Academic Needs Narrow	100	0	1	65	0.65(0.48)
Interaction with peers for academic purposes	100	0	1	11	0.11(0.31)
Interaction with staff for academic purposes	100	0	1	5	0.05(0.22)
Interaction with institution for academic purposes	100	0	0	0	0(0)
Need for four skills	100	0	1	37	0.37(0.48)
Technological needs	100	0	1	55	0.55(0.50)
Academic Needs Total	100	0	6	219	2.19(1.14)

The responses indicated that a significant percentage of participants in this study have an in depth understanding of the role played by language proficiency in attaining academic goals. In relation to science as a broad field of study (academic wide) learners showed a sophisticated understanding of the role played by English in the communication and dissemination of scientific knowledge. Learners thus showed an awareness of the need for a common language that could serve the needs of the scientific community. Learners were also able to cite specific areas such as scientific vocabulary that would require a common set of core terms to facilitate communication.

"*To interact/ communicate with the academic community in Sri Lanka and in the world"*

> *"Scientists will invent new things and new concepts, solutions and new unexplored things. With the use of their knowledge theyused to store their new inventions (inventions) and exploring in books. So therefore they must use a world language that anyone*
> *can understand".*

> *"Science is international. So there are many words in science subject in English such as chemical names. So we must know English well for understand and use correct vocabulary of names."*

Learners also showed an understanding of the pace at which new knowledge expands in the diverse fields of scientific research. It was also indicated that access to this knowledge was dependent on successfully accessing new technological resources which demanded competency in English.

> *"Science is a subject that is changing every day. So I should update my knowledge according to that. So if I am an expert in English I can go through internet and other resources and very easily update my knowledge."*

In addition to this understanding of the need for English to obtain scientific knowledge, a significant proportion of learners also showed an understanding of the importance of more particular and specific needs: in this case coping with the demands of the B.Sc. programme at OUSL.

> *"I have choosed a BSc degree at Open University for my higher studies. It's a valuable degree and the other important thing is we have to do it in the English medium."*

> *"We have to do this degree programme in English medium. Therefore our English knowledge is very essential for our studies."*

The motivation for learning English was also connected with a comprehensive understanding of the specific academic tasks that needed to be completed as part of their studies (academic narrow).

> *"it is very good opportunity have a good English knowledge to complete their projects, action researches and general researchers recommended by those degree programmes."*

The results revealed therefore that the category of academic needs was one of the chief factors that motivated learners to enhance their competency in language. Learner had a holistic understanding of the relationship between language and the development of scientific knowledge. They could also point out the specificities of language requirements in relation to the Degree

programme that they intended to pursue at the Open University of Sri Lanka.

Social Needs

In addition to the academic aspects that students cited as requiring enhanced language proficiency, learners were also aware of other dimensions that could be enhanced by the knowledge of English. Students cited social needs as one major factor that motivated them to develop their proficiency in English.

Table 3. *Descriptive Statistics for Social Needs*

	N	Min	Max	Sum	*M(SD)*
Social Needs-Recreational	100	0	1	28	0.28(0.45)
Social Needs-Communication	100	0	1	45	0.45(0.50)
Social- Personality Development	100	0	1	26	0.26(0.44)
Social Needs Total	100	0	3	96	0.96(0.76)

As shown in Table 3, the need to use English for social purposes was also expressed by the sample and these social needs were coded for three main categories. The highest number of instances was for the need to use English for Communication (for interpersonal interaction and for various other functions) while the need to use English for recreational purposes and for personality development was also felt by a considerable number of students.

Many learners felt that English was required to interact and communicate in a range of social contexts and situations. Some of these situations cited were pragmatic while others referred to general communication among family and peers.

"You may go on supermarket or silk shop or jewellery shop they speak on English. Then we want to have spoken English to that movement".

"When we are communicate with others we use some English words, even when we are talking Sinhala"

"I will try speaking in English with my parents, my sister and my friends"

One interesting facet that emerged during data analysis was that learners did not feel that English was required for day to day

communication within the academic institution. Learners did not indicate that English would be required to interact with their peers and the academic institution. This is a matter of some concern as communication within the institution would be one way of developing language skills to be used in other contexts.

Many learners also cited personality development as one area that required attention during the course of their university education. Enhancement of English language skills was seen as a means of developing self-confidence and dealing with challenging situations.

> *"I like to speak in English among others. When I speak in English feels to me to increase my self confidence."*
>
> *"When we speak in English our personality will also be colourful."*
>
> *"I think that if I know English with no any mistake I can face any challenge with no doubt."*

A small proportion of learners felt that English allowed them to participate in a range of recreational activities and leisure pursuits.

> *"I would like to read English novels, also like to watch English films and like to listen to English songs. So without learning English I cannot think about novels, films and songs"*
>
> *"I love to read books not only science but also almost anything. And I love to hear English music and subtitled English films"*

Thus, the analysis of data indicated that social needs (comprising a range of specific areas) were also another factor that motivated learning of English. These needs would necessarily have to be taken into account in the development of language enhancement programmes for this target audience. These expanding needs mean that programmes designed for university undergraduates would have to pay attention to reading, writing as well as speech and listening.

Occupational Needs

Table 4. Descriptive Statistics for Occupational Needs

	N	Min	Max	Sum	*M(SD)*
Occupational opportunities	100	0	1	40	0.40(0.49)
Occupational promotions	100	0	1	9	0.09(0.28)
Needs-workplace	100	0	1	22	0.22(0.41)
Occupational Needs Total	100	0	3	71	0.71(0.80)

As shown in Table 4, the need to use English for occupational purposes as stated by students had a mean of 0.71. They noted three purposes for which they would need English for. The need for having a good mastery of English was felt in finding good employment and these were coded as 'Occupational opportunities'. The highest mean was for that while the need for using English at the work place had the second highest mean. Not many students felt that English was necessary for their promotions.

Many of the participants cited future prospects in the job market as one of the benefits of competence in English. Overall, the responses indicated a connection between competence in English and the access to meaningful employment.

> *"Now a days English is a best qualification for a job*
> *And also after we complete our science course we go to the job market. Then again we need good English to get a good job"*

Participants also noted the fact that English would be of importance in gaining entry in to the job market by being able to perform successfully in examinations and interviews.

> *"In the present world most of the job interviews are conducting in English. We have to face for interviews and examinations and in these they measure our English fluency"*

It was also noted that fluency in English would also ensure a remuneration that was adequate and was commensurate with the skills demanded.

> *"People are paid fairly when they have English knowledge."*

The above statements show that these learners expect the English course to provide support in fulfilling their career aspirations as well. Hence, it is clear that these needs have to be taken into consideration when teaching English to these undergraduates. This would necessarily have implications for the content of courses in English language in academic settings.

It was also interesting to note that many participants were of the view that a degree in the field of science would be most marketable if it was in the English medium.

> *"Schools, universities, leading companies all over the world looking for the people who have accuracy in English in the relevant area."*
>
> *"Due to the high completion in the job market the people who have science knowledge with English only countable".*

The above findings show that the students have a wide variety of needs and interests. Almost all the students perceive English as an essential skill in pursuing their higher studies. However, their expectations of the English course are not limited to academic purposes. In addition to the support for developing skills for academic success, they expect the EGAP course to provide them with general communication skills. Some students are of the view that a course in English will help them improve their self-confidence and increase their employability and career promotions as well. Even though the results show that some students have high expectations they seem to have no clear plans for achieving them.

Perceptions of the Faculty on Students' English Language Needs

Being one of the main stakeholders, the views of the faculty of students' main academic discipline are important when designing an EAP course. The present study, therefore, attempted to explore the views of the Faculty of Natural Sciences on the English Language skills required by students in their academic work. More than 84% teachers were of the view that Reading in English is 'essential' for their students and 68% believed Writing in

English is 'essential'. The highest percentage for Listening was for 'moderately important' (47%) while Speaking was considered as 'somewhat important' by 37%.

Their views on the need for performing different tasks in Reading, Writing, Listening and Speaking for academic study were also investigated through a questionnaire. Reading textbooks (78.9%), Reading assignments, examination papers and lab manuals (68.4%) were considered as the reading tasks the students engage in 'to a great extent' while Reading journal articles (5.2%), and Reading from other sources *i.e.* internet (26.3%) were not seen as academic asks students perform in English to a great extent. A majority of teachers (42.1%) believed writing a long essay (about ten pages) as a task their students perform 'to a little extent' while writing short essays was believed to be done 'to a great extent'. According to them, English is mostly used when writing answers to examination papers (68.4%) but not when writing for personal use (*i.e.* making notes) or for non-academic purposes. Listening to lectures (63.1%) and instructions (47.3%) in English were thought to be done by students to a great extent while watching videos, listening to audio cassettes were not considered as activities done in English to a great extent. In Speaking, most of the skills i.e. making presentations, asking and answering questions, engaging in discussions, giving directions and interacting with staff and peers were thought to be performed in English only to a little extent. Less than 15% of the teachers believed that these activities were performed in English by their students to a great extent.

The study also investigated the views of the faculty on the importance of the different aspects of English language skills when students perform their academic activities.

As shown in Table 5, critical reading, listening efficiently, use of appropriate vocabulary, ability to summarize/paraphrase, writing grammatically without plagiarizing were considered as essential skills while speaking fluently and accurately was also regarded as important in students' academic work. However, there was a fair percentage of teachers who did not give much importance to speaking fluently/accurately, pronunciation, writing grammatically and spelling and punctuation. Answering the open ended questions, some teachers expressed the view that students' reading and writing skills improve when they learn in the medium of English and more attention needs to be paid to speaking. Facing a viva/interview successfully, presentation skills and the ability to write project reports are pinpointed by some teachers as

important skills for final year undergraduate students.

Table 5. Perceptions of the academics in the main disciplines on aspects of English language skills

	Essential %	**Important %**	**Somewhat important %**	**Not important %**
Writing grammatically	42.1	26.3	26.3	5.2
Spelling and punctuation	36.8	36.8	21.0	5.2
Use of appropriate vocabulary	47.3	42.1	5.2	5.2
Avoiding plagiarism	57.8	26.3	5.2	5.2
Reading critically	73.6	15.7	5.2	5.2
Summarizing/paraphrasing	47.3	42.1	5.2	5.2
Listening efficiently	57.8	36.8	5.2	0
Speaking fluently	10.5	52.6	31.5	5.2
Speaking accurately	21.0	47.3	26.3	5.2
Pronunciation	15.7	42.1	36.8	5.2

The results, thus, show that the expectations of teachers in academic departments about their students' English language skills are fairly high and these are mainly for academic work. Students, however, have expressed their need to use English not only for academic purposes but also for social and occupational purposes. Addressing these diverse needs is a challenge faced by Departments of English that offer English language support to thousands of students in a year.

Conclusion and Recommendations

The results indicate that students have a wide range of needs, which includes academic, occupational and social needs, which they hope to fulfil by following the EGAP course. This diversity of needs has implications for the future development and delivery of the EGAP course.

One initial question that needs to be addressed is to what extent the EGAP approach is appropriate to the present context. Given that students have such a wide spectrum of needs which includes

subject specific English language skills that meet their short term needs as well as their long term career prospects, it is important to further examine the theoretical foundations that underpin an EGAP course. The adequacy of the present approach to course design, which Hyland (2012) characterizes as "broad literacy domains " or "non-specific ESP ", needs to be examined in the relation to the findings of student needs. It is important, therefore, that course developers continue to align the goals of this course with the needs of students who are involved in learning a variety of disciplines. This would ensure that the course in fact addresses the needs of the target audience.

Fundamental to the success of the EGAP course is the competencies of the teachers who are responsible for the content of the programme. Thus the English language teacher would be primarily responsible for training students in adapting macro linguistic skills to their specific purposes. As Chien and Hsu (2010) note, "ESP is well known for its learner-centered and content-based approach. Thus the ideal ESP teacher must not only be skilful in the English language, but also acquire the knowledge of a specific profession in order to provide an effective ESP course for the learners". Practically such a teacher is seldom to be found in a regular university setting" (p.1885). As has been noted in other ESL settings, it has proved extremely difficult to recruit and retain teachers with such a broad range of competencies. It is essential, therefore, that those teachers be given further opportunities to enhance their skills to successfully deal with the challenges of teaching in the EGAP classroom. It is also important for teachers to be made aware of the wide range of needs of their students.

One major pragmatic challenge that has been noted in previous studies, (Evans and Green, 2000) which is pertinent to the present research as well, is that of responding to a range of needs given the limited contact hours allocated for English language teaching in the context of a large institution like the Open University. This problem is further exacerbated by the fact that adult students who have competing demands on their time as they are balancing studies, jobs and family lives, are also not in a position to spend much time on face to face contact sessions. Given the multiplicity of needs that are posited by students and staff, and the limitations faced by students, it is essential that needs be prioritized in deciding which particular needs would be addressed by the proposed EGAP programme in the limited time span that is

allocated. It is also important to revise materials further in a manner that fosters independent learning to a great extent.

Coping with these challenges would require academic staff in English language teaching department to re-examine the resources and opportunities that are currently available. Flexibility in learning through online virtual language courses would be an ideal solution for meeting the wide variety of needs of EAP students learning in the Distance Mode. A blended mode of delivery which comprises both the traditional forms such as printed course material along with online elements could be initially adopted as a possible solution. However, limited/no access to internet in rural areas, high costs in broadband connection, and non-familiarity with ICT (especially the older students) may affect student participation in such courses. Time constraints and lack of resource personnel with e-confidence for course design are major challenges in achieving this goal. Most of the students lack transversal competencies i.e. goal setting, self-monitoring, reflection and other learning to learn skills and strategies which make them unprepared to cope with the challenges in using their L2 for higher education, especially in a Distance Education environment. Hence, future courses in EAP need to focus on these issues as well which may support the acculturation process of students in the new environment.

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Identifying the Impact of Temperature and Water Stress on Growth and Yield Parameters of Chilli (*Capsicum annuum* L.)

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Abstract

The effect of climate change on global food security has assumed a frightening dimension in developing nations. The need for efficient management to cope with the effect of climate change became imperative. The main aim of this research is to compare the growth and yield parameters of Chilli when it subjected to temperature and water stress. Experiments were conducted on the growing seasons of 2010 and 2011 at the Open University Sri Lanka Agricultural field located at Nawala, Nugegoda using Chilli Varity MI-2 in temperature regulated polytunnels. Split plot experiment based on Completely Randomized Design with 10 replicates was applied as an experimental design. Main plot included two different wetting applications (No water stress-at field capacity level and water stress at 50 % depletion from the field capacity level) and sub plots contained 3 different temperature regimes (34 °C, 32 °C temperature and ambient temperature).

According to the results the temperature stress has especially affected the plant height, branches, canopy diameter and number of fruit weight at 0.01 probability levels. Further temperature stress showed significant effect at 0.05 probability level on transplant success, fruit diameter and number of fruits per plant. According to the yield parameters it was observed that interaction effect of the stresses of temperature and water had higher significant impact on growth and yield of Chilli. Yield reduction of Chilli due to temperature stress can be overcome by providing water at field capacity level of the soil moisture during growing period.

Keywords: soil moisture, temperature stress, water stress, growth parameters, yield parameters

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Introduction

One of the most fundamental questions facing humanity today is global warming and how the humanity will face it with respect to increase food production. Up to now model-based research on climate impact on regions dominated by agriculture mostly deals with yield development, landscape water balance, nutrient dynamics and nutrient loads or endangerment of habitats separately. Higher temperature in next decades implies higher evaporation and therefore higher water demand for the crops will be expected. The phenological development rates of the crops will increase due to the higher temperature and an increase of temperature as well as water stress can be expected.

Fernando and Chandrapala (1996) showed that the amount of rainfall received by the country has been declining gradually. For example, the average annual rainfall which amounted to 2005 mm during 1931-1960 had declined to 1861 mm during the more recent (1961–1990) period. Long term temperature trends reveal a rise in temperature by 0.016 °C per year in 14 Meteorological stations during the recent 30 year period (Fernando and Chandrapala, 1992). Punyawardana (2002) reiterates that an increase in temperature in Sri Lanka would affect the high value vegetable and potato cultivation in the central hill country and the cool season potato and other vegetables cultivation in the Jaffna peninsula, if night time minimum temperatures continue to increase. Consequently yield per unit area would be lower; resulting in an increase in the water demand of rain fed and irrigated crops as well as an increase in the potential evapotranspiration.

Justification of this study

Studies in Sri Lanka based on HadCM3 general circulation model has revealed that the temperature will increase in coming years and in 2050s the highest temperature increase by 2^0C in predicted in Anuradhapura compared to the baseline temperature of 1961-1990 (De Silva 2006). The rainfall during northeast monsoon is predicted to decrease in dry zone area. Therefore the decreased rainfall and increased in temperature will increase the evapotranspiration and soil moisture deficits. Agricultural activities in the dry zone may be affected by predicted climate change in Sri Lanka (De Silva *et. al.,* 2007). Therefore this

research aimed to determine the effect of high temperature and water stress on growth, yield and quality parameters of Chilli variety MI-2.

Chilli (*Capsicum annuum* L.) has its unique place in Asian diet a spice as well as a vegetable. It is also a high value crop commercially grown in Sri Lanka. Chilli is grown as a mono crop in most of the dry zone areas and the harvest can be sold as fresh or dried. Because dry chilli fetches high prices, farmers used to dry their harvest and to sell it when the prices are high. Due to these farmers grow Chilli in large extents. With the growing concerns of climate change with varying temperature and water stresses, it is important to study how Chilli plants behave under high temperature and water stress conditions. This study is focused to understand the impact on growth and yield parameters of Chilli when exposed to temperature and water stress conditions and to suggest possible adaptation measures.

Methodology

The study was conducted at the Open University Sri Lanka, Nawala, Nugegoda from September 2009 to April 2011 for the consecutive 3 seasons. The cultivar MI-2 of Chilli was used in this study; this cultivar is currently recommended by the Department of Agriculture for production in Sri Lanka. All the plants were planted in pots filled with reddish brown earth (Figure 1).

Simulated environmental conditions

Polytunnels were constructed in order to maintain the stipulated temperature conditions by means of thermostat and air circulation fans (Figure 2). One set of polytunnel was maintained at 32 °C maximum temperature. And the other set of polytunnel was maintained at 34 °C upper limit through out the growing seasons. When the temperature increases above the respective maximum temperature, the fans starts to operate until the temperature is controlled to the maximum temperature fixed by the thermostat for that particular polytunnel.

Figure 1. Pots arrangement **Figure 2.** Poly tunnels

Experimental Designing

The experiment was laid out in split plot experiment based on completely randomized design with ten replicates for the main plot treatment. Main plot included two different soil moisture conditions such as field capacity (no water stress) and 50 % of the field capacity level (with imposed water stress) and sub plots containing 3 different temperature regimes such as 34 °C maximum temperature poly tunnel, 32 °C maximum temperature poly tunnel and ambient temperature at open space. Soil moisture measurements were carried out using tensiometer. The soil water content in half of pots was kept at field capacity by compensating the loss in weight by adding water. Physiological and morphological parameters of Chilli were investigated during the growing and reproductive periods.

Chilli was raised in a nursery and transplanting was conducted 4 weeks after planting (4WAP). According to the Figure 3 half of Chilli plants in each temperature block were subjected to water stress until they reached relative soil water content (RWC) of 50%. It was done using the Soil tensiometer. In the open space (Ambient temperature) cultivation with water stress and without water stress were practiced as a control. Further in the open space the water stressed plants were under the cover so that 50% soil moisture depletion could be maintained. Regular management

practices (Fertilization, weeding *etc.*) were adopted except water management.

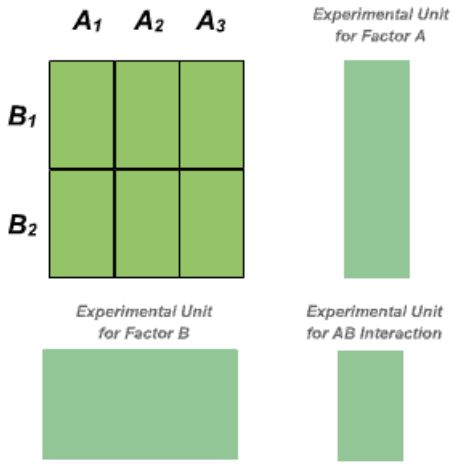

Figure 3. Experiment lay out

Periodic non-destructive measurements were carried out on the same plants to monitor the effects of temperature, and water stress on shoot growth. As for the plant physiological parameter measurements, plant height was measured from the shoot apex down to the base at the soil surface level, pod length were measured using measuring ruler, pod diameter was determined using vernier calliper while number of pods per plant and number of leaves per plant was counted.

The number of leaves on the main stem (primary leaves) and the rest of the leaves on the shoots subtending the primary flowers which were longer than 1 cm (secondary leaves) were counted and totalled to determine effects on leaf initiation. The measurements included the total numbers of flowers and flower buds and the time required to reach anthesis or abscission. From these observations, the percentages of flowers abscising or reaching pod setting were calculated. Average weight was determined of matured green fruits from the second harvest. Measurements were taken weekly till the end of the growing season.

Statistical Analysis

All extraction runs and analyses were carried out at least in duplicate and in randomized order with the mean values being reported. Analysis of variance (ANOVA) of the results was performed using General Linear Model procedure of SPSS (Software Version 19). Multiple comparison of the various means were carried out by LSD (Least Significant Difference) test at P = 0.05 and p = 0.01.

Result and Discussion

Temperature control inside the polytunnels

Figure 4 shows the variation of temperature inside the poly tunnel and the ambient temperature outside over a period of 24 hours. Even though the sensors and exhaust fans used to maintain temperature inside the poly tunnels the temperature during night time falls below the maximum temperature set for that particular poly tunnel. However, the temperature maintained inside the polytunnels was always higher than the ambient temperature; therefore temperature stress was imposed on the plants throughout the day.

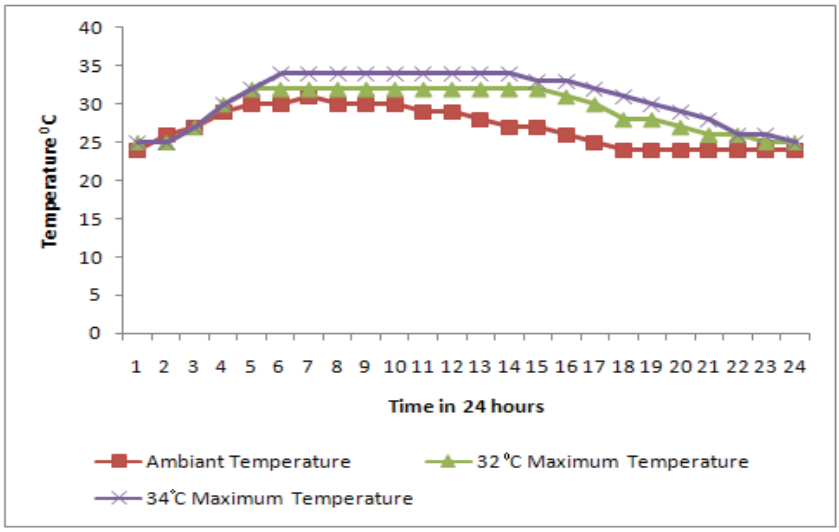

Figure 4. Average Temperature variations inside and outside the poly tunnels within a day

Temperature and water stress on the growth parameters of Chilli

1 Transplant success and shoot growth

Abiotic and biotic stresses cause alterations in the normal physiological processes of all plant organisms, including the economically important crops. Plant damage and decrease in their productivity take place due to naturally occurring unfavourable factors of the environment such as extreme temperatures, water deficit. Analysis of variance showed significant difference for most of the characters (Table 2) both individual stresses as well as combined stress.

The highest transplant success (98 %) was reported at 32 °C maximum temperature polytunnel without a water stress condition (Figure 5). Chilli MI-2 is a dry zone cultivar and which has high plant vigour. Although it has good vigour it shows highly significant (P = 0.01) effect of individual water stress on transplant success and individual temperature stress also showed significant influence at 0.05 probability levels. Lowest transplanting percentage was shown at the 34 °C maximum temperature combined with the water stressed and this interacting effect also highly significant at the 0.01 probability level. However, interactive effects of the both temperature and water stresses were showed critical effect for the survival after transplanting. Interactive stress effect may reduce the probability of plants establishment because of the effect of high temperature results in low soil water conditions, and that affect on survival of young plants.

2 Plant height and canopy diameter

Average plant height among the treatments ranged from 28-70 cm (Table 1) and generally, a reduction in height is the plant's first response to water stress giving highly significant (P = 0.01) negative growth with the individual water stress effect. Further the average of the three seasons mean results shows that individual temperature stress has highly significant (P = 0.01) positive growth effect on the plants under the indoor condition. It is interesting to notice this interaction effect of both temperature and water stresses severely and negatively affect for the plant growth (Figure 6).

Table 1. Variations of crop characters of chilli under stress

Treatments	Leaves/ plant	Plant height(cm)	Branches /plant	Canopy diameter (cm)	Translating success %	Fruit Diameter (mm)	Fruit weight (g)	Yield /plant(g)	fruits /plant	Fruit length (mm)	Fruit setting %
Ambient tem. No water stress	108	43	27	28.5	91	8.17	4.76	233.24	49	37	56
Ambient tem. 50% water stress	97	40	28	24.6	83	7.35	3.6	151.2	42	33	32
32^0C Max. tem No water stress	114	58	25	41.6	98	8.15	4.78	243.78	51	37	45
32^0C Max. Tem 50% water stress	96	38	34	28.5	82	7.12	3.65	131.4	36	32	28
34 ^{0}C Max. Tem No Water stress	136	70.7	27	43.8	95	8.63	4.98	268.92	54	43	52
34^0C Max. tem 50% Water stress	64	28.9	35	21.4	76	6.06	3.22	99.82	31	28	12

Table 2. Analysis of variance of temperature and water stress on some traits

		MS										
Source of variation	df	Leaves/plant	Plant height (cm)	Branches/plant	Canopy diameter (cm)	Transplanting Sucsess (%)	Fruit Diameter (mm)	Fruit Weight (g)	Yield/plant(g)	fruits/plant	Fruit length(mm)	Fruit Setting (%)
Main plot trt (WS)	1	6013.38**	2206.69**	200**	664.90**	709.38**	9.9**	4.090	53436.16**	982.72**	162**	2812.5**
Sub plot trt (TS)	2	11.06	112.36**	24.05**	83.46**	13.72*	0.28*	0.31**	216.148	7.88*	19.056	46.722
Interaction Effect WS*TS	2	1586.72**	518.61**	29.16**	86.27**	37.38**	1.11**	.291	1143.5*	104.22**	36.16*	160.16*
Error	12	7.44	3.670	.660	1.451	3.111	.039	.141	134.963	.889	5.778	13.444

* indicates significant at the $0.01 < P \leq 0.05$ probability level; and ** indicates significant at the ≤ 0.01 probability level

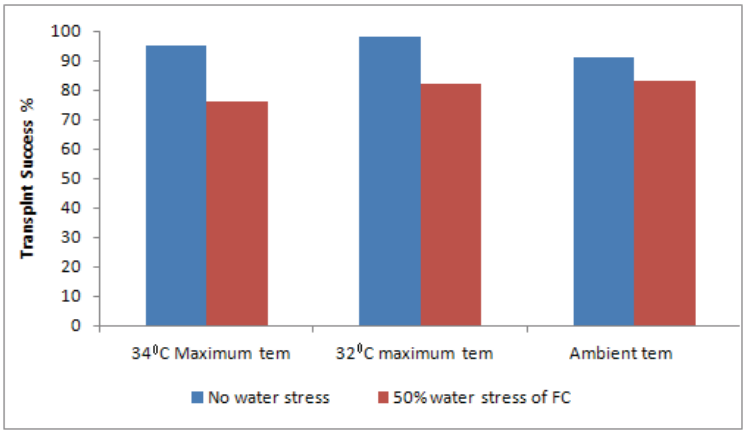

Figure 5. Effect of treatments on average percentage of transplant success

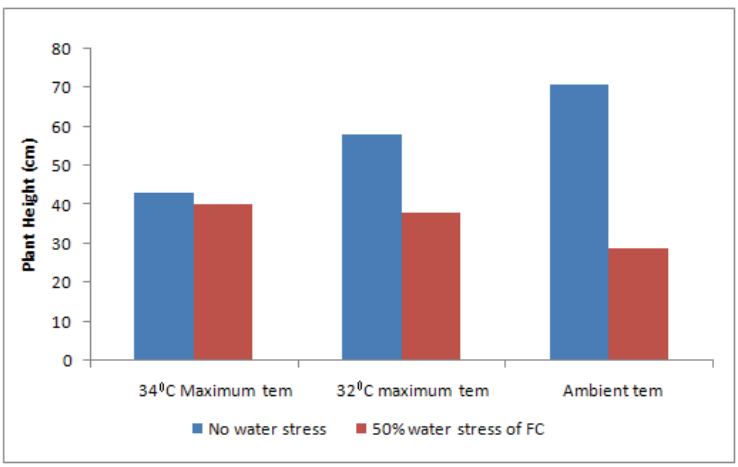

Figure 6. Effect of treatments on average plant height

For the canopy width, the 34°C maximum temperature no water stress treatment shows significantly (P = 0.05) highest comparative to the other treatments (Figure7). Yield value indicting a well spread canopy, which contributes directly to the yield.

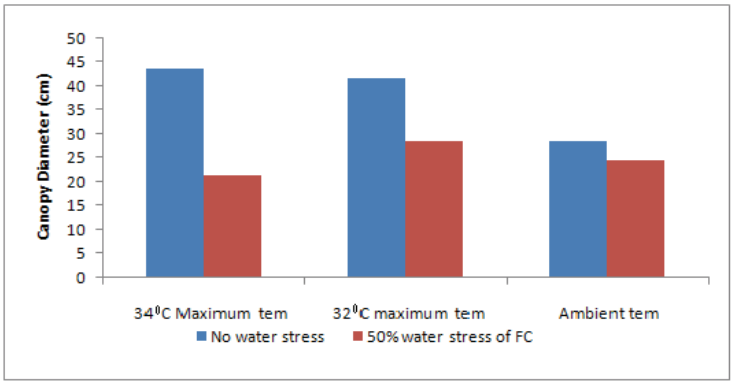

Figure 7. Effect of treatments on canopy diameter

3 Branches and leaves production of the plant

Total leaf number (Primary and secondary) was significantly affected by individual water stress effect and interaction between water stress and temperature stress. The highest number of leaves was recorded at 34 °C maximum temperature under no water stress conditions (136 leaves plant''), whilst only 64 leaves plant'' were produced at 34 °C and water stressed condition and which was the greatest retardation due to the both temperature and water stress effect (Figure 8). Analysis of variance was proved that individual water stress had significantly ($p = 0.01$) affected the leaf production and interaction effects of both temperature and water stress also showed the same effect. But the results show that there is no significant effect of temperature stress only on the production of leaves.

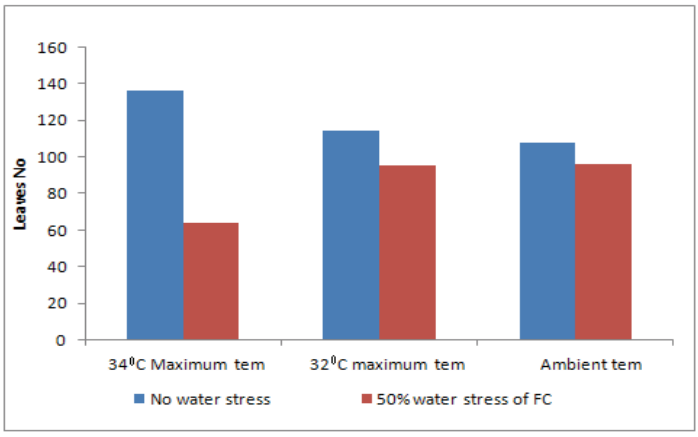

Figure 8. Average number of leaves production

Average branch production among the 6 treatments is shown in the Figure 9. According to the statistical analysis it is clearly shown that water stress and interaction effect of the water and temperature stress stimulate significantly (P=0.01) the branch production. But the temperature stress alone negatively affect on branch production. It is well documented that expansion growth is extremely sensitive to water stress (Hsiao *et al.*, 1985; Hsiao and Jing, 1987) and that restriction in leaf expansion is one of the first symptoms of water stress (Kirkham, 1990).

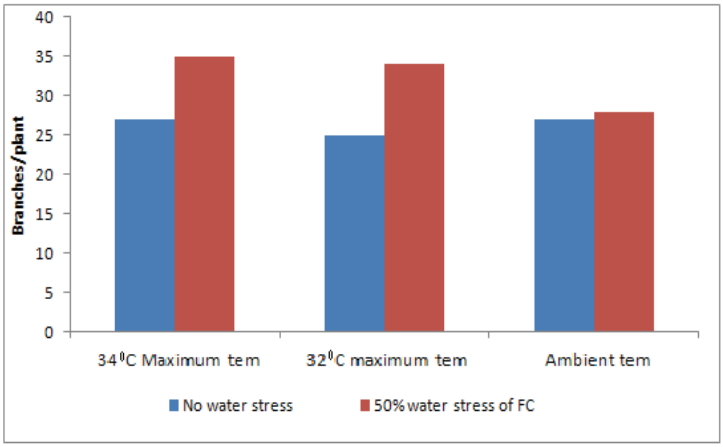

Figure 9. Average branch productions

Temperature and Water stress on yield parameters of Chilli

1 Flowering and setting of the fruits

Flowering of Chilli variety MI-2 was obtained at 6 week after planting and continued for a period of 3 months. Flowering at 34 ^{0}C maximum temperature in water stressed treatment took place 8 days earlier than the other treatments. Emergence of the first primary flower bud was accelerated more by the combination of high temperature (34 °C) and water stress. High temperatures generally increase the rate of flower development, resulting in earlier anthesis (Kinet *et al.*, 1985). Plants which were exposed to high temperature and water stress completed its life cycle much faster than other treatments. In determinate annual species warmer temperatures increase the rate of ontogenetic development and results in substantial shortening of the growth

period. This results in less time for carbon fixation and biomass accumulation before seed set (Pinter *et al.* 1996, Morison 1996).

In our study Chilli plants under went considerable variation in the number of flowering which set fruits under different treatment conditions (Table 1). Here maximum fruit setting was shown in the ambient temperature no water stress condition and individual water stress was shown highly significant (P = 0.01) effect on the fruit setting. Our study statistically showed that fruit setting did not differ significantly among the temperature treatments. The adverse effect of high temperatures after anthesis is also well illustrated by greenhouse-grown sweet pepper (Song *et al.* 1976) as the percentage abscission increased with complete abscission of flowers and buds when exposed to 35 °C. In our study interaction stresses showed significant reduction of fruit setting at 0.01 probability level. Gopalaratnum (1933) was observed that high temperature, low soil moisture and low atmospheric humidity were responsible for a low percentage of set fruit.

2 Number of pods per plants and pod yield

The number of fruit is an important yield component of Chilli to achieve highest yield. According to Table 2 water stressed condition had significantly ($p < 0.01$) affected the number of fruits per plant. Further the Figure 10 shows that the highest temperature stress with adequate soil moisture at field capacity level has increased the number of fruits per plant compared to the other treatments significantly ($p<0.01$). The highest number of fruits per plant (6.6) was found with high temperature (34 °C) with no water stress treatment and which was followed by 32 °C temperature with no water stress condition. The number of fruits per plant was lowest when Chilli was subjected to water stressed conditions. Drought occurring during vegetative growth period is called as vegetative phase drought. This type of drought affects plant's assimilatory organs, which usually decrease in number and size resulting in lower photosynthates production (Kaiser, 1987; Chaves, 1991; Larcher, 1995; Chaves *et al.* 2002). As a result yield decreases due to less amount of assimilate available to the developing pods.

However it is interesting to note that even the highest temperature and water stress has lowest number of fruits per plant compared to other water stressed treatments. It shows that the combination stress effects of temperature and water have

higher negative effects on number of fruits per plant in Chilli compared to the individual water stress treatments.

The fresh fruit yield is the most important character when considering the economic importance of this crop. These results showed that individual water stress had highly significant ($P < 0.01$) negative effect on production on the plants. Similar results were obtained byAde-Ademilua*e.al.* (2009) in his study because there is a direct relationship between quantity of water used by the crop and yield.

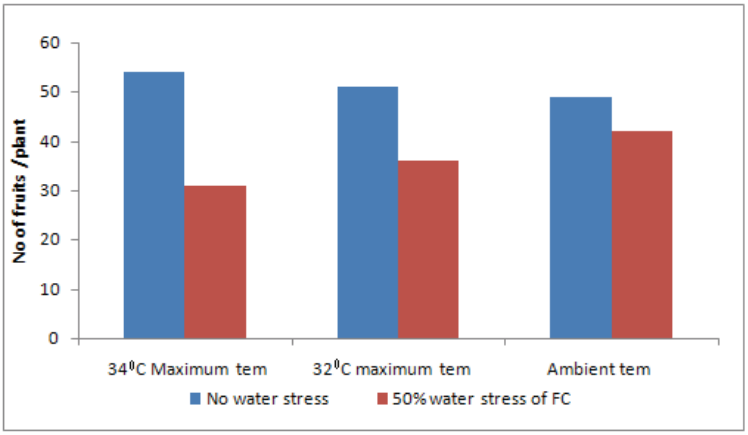

Figure 10. Effect of treatments on average no of fruits/plant

There is no significant reduction of mean yield when Chilli plants grown in high temperature (34 °C) condition without water stress condition (Figure 11). According to Table 1 Chilli yield can be improved under high temperature (34 °C) by giving adequate water for the plant growth. Although Chilli plants shows significant yield reduction with combined stress effect, overall yield can be recovered from the damage caused by temperature stress by providing water to maintain the soil moisture at the field capacity level.

Fruit length and individual fruit weight were higher (Table 1) in the plants grown under high temperature (34 °C) condition under no water stress condition. The highest number of fruits per plant was shown when plants grown at 34°C maximum temperature condition without water stress. Generally the yield of Chilli grown under 34 °C temperature was (292 g/plant) which is higher than the other treatments. The lowest significant yield was observed in high temperature polytunnel (34 °C) under 50 % water stressed

condition. According to the results, the interaction between high temperature and water deficit affects the yield of Chilli than the individual stress of either temperature or water. Similarly Delatorre (2008) demonstrates that interaction between high temperature and water deficit affects photosynthesis responses greater than the individual stresses. In high temperature conditions the negative influence of environmental stresses such as water stress will be exacerbated and the current vegetation and yield may undergo major drawbacks (Centritto *et al.*, 1999c; Centritto, 2002).

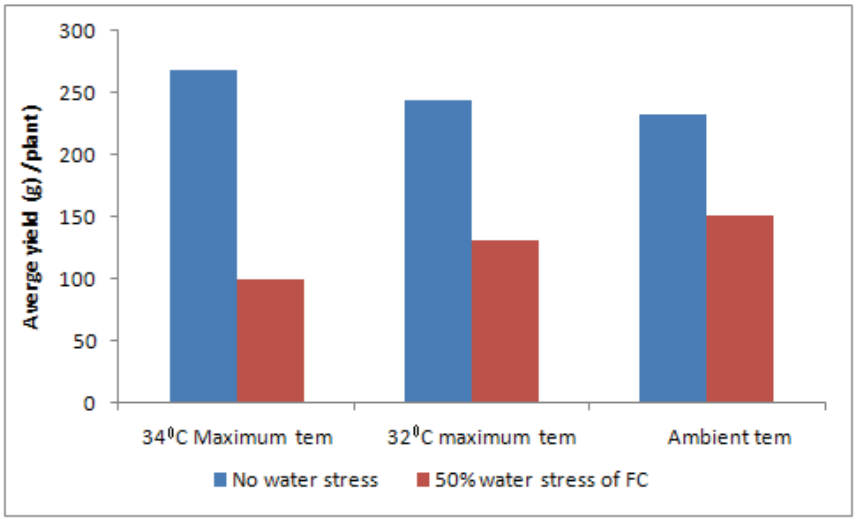

Figure 11. Effect of treatments on average plant yield

3 Fruit diameter and fruit length

When plants were exposed to 34 °C maximum temperature and no water stress condition the diameter of the pods were rapid in growth and reached the maximum. Both individual stress as well as the interactive stress has high significant influence ($p < 0.01$) on the pod diameter (Figure 12).

The fresh pod length was affected significantly ($p < 0.01$) in individual water stress. The interactive stress effect significantly reduces the fruit length on the 0.05 probability level (Table 1 and Figure 13).

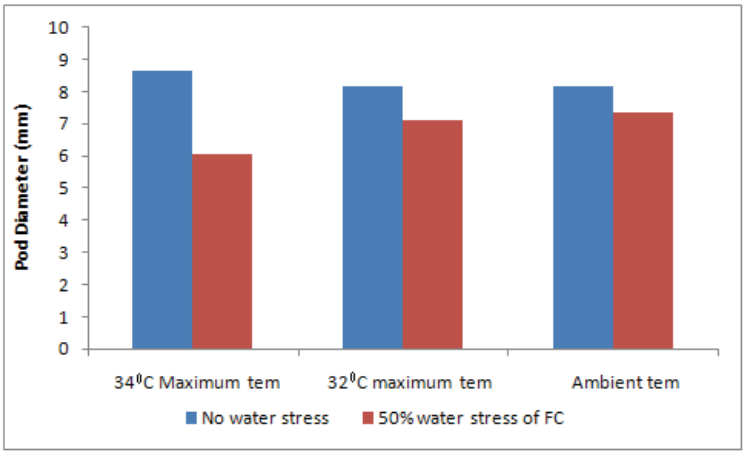

Figure 12. Effect of treatments on fruit diameter

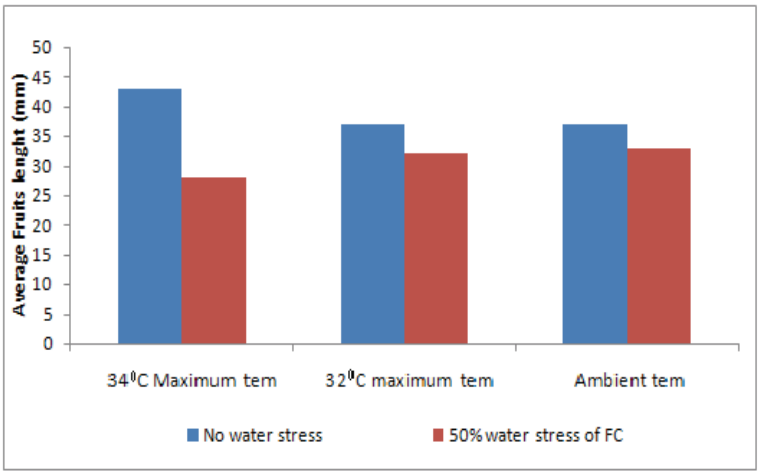

Figure 13. Effect on treatments on fruit length

4 fruit weight

The treatments (Table 1) are highly significant on the ($p < 0.01$) fresh and dry weight of Chilli pods under individual water stresses. In the case of dry matter of the fruit the maximum weight was observed at the 34 °C temperature with no water stress condition. Even the combined effect of high temperature (32 °C) and water stress had the remarkable effect on the fruit weight of Chilli compared to the other treatments (Figure 14).

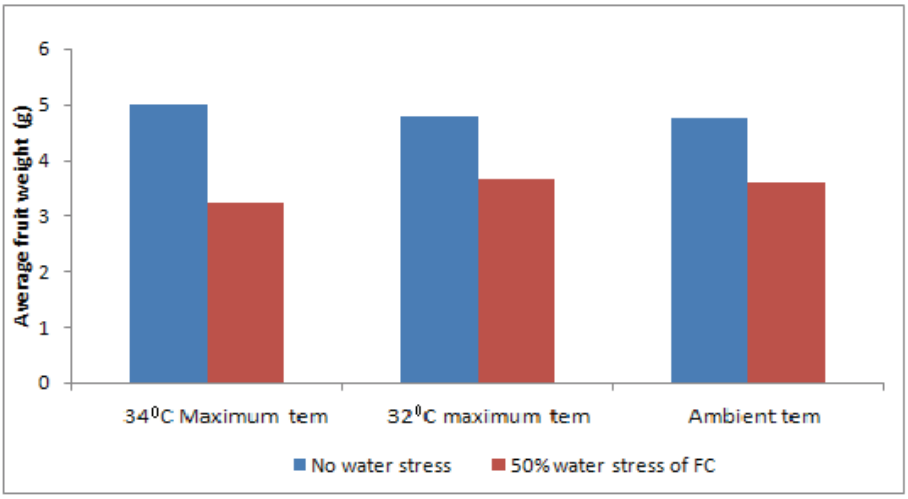

Figure 14. Effect of treatments on average fruit weight

Conclusion

The sustenance of Chilli production to Sri Lanka is very important to improve agricultural productivity with the future changing climate. From the study, it was observed that interaction effect of the stresses of temperature and water had higher significant impact on growth and yield of the Chilli crop. The Chilli variety MI2 could be identified from this field experiment for water stress tolerance and survival. Yield reduction of Chilli due to temperature stress can be overcome by providing adequate water to the plants without water stress in the soil zone during growing period. This study might serve to understand the adaptation applicability for in the context of global warming.

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Simulation of Potential Groundwater Recharge from the Jaffna Peninsula of Sri Lanka using HYDRUS-1D Model

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Abstract

In drier regions, accurate knowledge of groundwater recharge is important for the sustainable management of scare water resources. Thirunelvely in Jaffna Peninsula is an area where groundwater is being utilized for domestic, agricultural and municipal water supply. Further the groundwater in this area also contaminated with nitrogenous fertilizer application due to intensive agriculture, as post war conditions in the Peninsula encourage farmers to engage in intensive agricultural activities. Very few or no studies have been conducted in the recent past on groundwater recharge or solute transport such a fertilizer leaching in this area. HYDRUS-1D is a Windows-based modelling environment for analysis of water flow and solute transport in variably saturated porous media. HYDRUS-1D is just as quick and cheap as other soil moisture balance models but more physically based and flexible as it allows for building up complexity as data are available whether for solute transport or non-equilibrium flow etc. Therefore the main objective of this paper is to simulate potential groundwater recharge using HYDRUS-1D and compare it with the results obtained in Thirunelvely using soil moisture balance and water table fluctuation methods. Results have shown that the HYDRUS-1D simulated potential groundwater recharge (41.8 cm) has close agreement with that estimated by other methods with high coefficient of determination ($R^2 = 0.95$). Further runoff, soil moisture storage and bottom pressure head simulated by HYDRUS-1D too have good agreement with field observation. Therefore HYDRUS-1D is capable of simulating potential groundwater recharge close to the previously estimated values in Thirunelvely as it has good agreement with the water table fluctuation measured in the study site and the bottom head pressure at the 1 m soil profile simulated in the HYDRUS-1D model. Now that it has been demonstrated that HYDRUS-1D adequately reproduces the water fluxes predicted by other

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methods, it could be used for groundwater recharge with more confidence and to investigate pollution in soil zone and groundwater.

Introduction

Estimating groundwater recharge is important for management of water resources and aquifer vulnerability to pollutants (Scanlon and Cook, 2002). Recharge estimation can be difficult in areas where groundwater tables are typically deep. The recharge rate is limited by the availability of the water in the soil surface which is depend on the temporal and spatial variation of climatic factors such as precipitation, temperature and evapotranspiration (Scanlon and Cook, 2002).

Knowledge of groundwater recharge is essential in virtually in all groundwater hydrology investigation and it is depending on the application, which needs to be estimated at a variety of spatial and temporal scale as stated by Delin *et al.* (2007) and Scanlon and Cook (2002). While groundwater recharge is one of the most important parameters required to support sustainable management of groundwater resources, it is one of the most difficult to evaluate accurately, due to the numerous factors involved in recharge processes. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Thus, a quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for operating groundwater resources system in an optimal manner.

Groundwater recharge is that amount of surface water which reaches the permanent water table either by direct contact in the riparian zone or by downward percolation through the overlying zone of aeration (Rushton and Ward, 1979). Also De Vries and Simmers (2002) defined groundwater recharge in a general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. It really expresses the total quantity of groundwater resource available and their supply potential. Recharge is the quantity which may be available in the long term for abstraction and is therefore of prime importance in the assessment of any groundwater resources management.

Methods such as soil moisture balance, chloride profile, water table fluctuation and several other methods of estimation of

groundwater recharge are been reviewed with varying degrees of success (Scanlon and Cook, 2002; de Vries and Simeers, 2002). These methods can be grouped in to three based on whether the focus of the method is surface water, the vadose zone, or saturated zone. Further most of the recharge estimation models are basically simulating only water flow and a very few for both water and solute flow. Therefore, the objective of this study is to simulate potential groundwater recharge using HYDRUS-1D which can be used to estimate the potential groundwater recharge with the intention of using the model to simulate solute transport in the future. The modelling approach used HYDRUS-1D (Šimůnek *et al.*, 2005); a well known numerical computer model that simulates water, heat and solute movement in variably saturated porous media. This study also provides an opportunity for comparing recharge rates estimated with modified soil moisture balance (MSMB) method and water table fluctuation method (WTF) by Mikunthan and De Silva (2009) at similar sites.

Further HYDRUS-1D is a full physical process model available, and therefore should be the best if parameter values can be estimated well enough. Overall no method is perfect, and inter-comparisons are useful. HYDRUS-1D is also just as quick and cheap as MSMB but more physically based and flexible as it allows for building up complexity, as data are available whether for solute transport or non- equilibrium flow. In this study HYDRUS -1D is used only for water flow.

Study Site Description

Thirunelvely was selected in this study because it has received much attention due to its significant groundwater dependence, groundwater being utilized for domestic, agricultural and municipal water supply: the assessment of groundwater recharge plays major role in the management of water supply schemes such as this one. Thirunelvely, an intensive farming village of Jaffna district and located in Nallur divisional secretariat was considered for the simulation of potential recharge using HYDRUS-1D. The Jaffna Peninsula is situated at the Northern extreme of Sri Lanka. Geographically confined to North and East by the Indian Ocean, to the West by the Palk Strait and to the South extending to the mainland of the country (Figure 1), the Jaffna district occupies an extent of 1023 km^2, which includes inland waters. Farmers in Thirunelvely are cultivating agricultural crops such as red onion, chillies, potatoes, tobacco, cabbage, leafy vegetables, banana and

grapes for commercial purposes. Nagarajah *et al.* (1988) reported that high levels of organic manure such as cattle, goat and green manures and inorganic fertilizers and agrochemicals are applied to these high value crops. Other crops such as paddy, pulses and coconut are also cultivated in the study area. The population density of Nallur divisional secretariat is 1920 person/km^2 the second highest population density area in the Jaffna district. The Jaffna municipal area receives drinking water from three major water supply schemes including the old and new Thirunelvely schemes. The extent of the study site at Thirunelvely is 342 ha. The elevation of the study area is 8 m above the mean sea level. The site is flat and slightly undulating with only 2 % slope and consists of red yellow latosols (red earth) occurs as a thin layer (0-2 m) on the surface of the Jaffna limestone (Arumugam, 1970). The description of the study area is shown in Figure 1.

Thirunelvely experiences typical dry zone climate of Sri Lanka, characterized by a wet and a dry season. The major rainy season occurs during October to February due to the 2nd inter-monsoon and North-East monsoon and the minor rainy season occurs during April and May due to the 1st intermonsoon. Thirunelvely is located in DL_3 agro climatological region of the dry zone, which receives an average rainfall of 1300 mm annually (Arumugam, 1970). Months of September/October to January/February and February/March to August/September are called *Maha* (wet season) and *Yala* (dry season), respectively. The bulk of the rainfall is received during the months from October to January and with little or no rainfall afterwards. The estimated 75% probability rainfall in this district is 510 mm in *Maha* and 102 mm in *Yala* (Cooray, 1984).

The Jaffna Peninsula is unique in geology and aquifer conditions. The northern and northwestern coastal belt of Sri Lanka (stretching from Puttlam to the Jaffna Peninsula) represents the major sedimentary formation of the island. This formation mainly consists with Miocene Limestone (Cooray, 1984). In general, this Miocene formation unconformably overlies high-grade pre-Cambrian metamorphic rocks (the Wanni complex, formerly the West Vijayan complex) but in places is underlain by sedimentary layers of Upper Jurassic (Gondwana) age (Arumugam, 1970). Lithologically this limestone is off white or cream coloured varying from white grey to light brown, compact, highly karstic, indistinctly bedded and partly crystalline (Arumugam, 1970). It also contains sandy (siliceous) friable layers with cavities

(Arumugam, 1970). The vertical thickness of the Miocene limestone exceeds 35 m (Arumugam, 1970). In the north-east the limestone scarcely crops out, but there are a number of karstic features including surface depressions (*e.g* at Manipay Idikandu), tidal wells (Puthur Nialvarai), cliffs and springs (Keerimalai). The limestone is generally overlain by highly porous thin (maximum 2 m) soil cover of red earth (Rajasooriyar *et al.*, 2002).

The water table in this unconfined aquifer responds to the onset of monsoon rains and shows a more peaked response than the underlying limestone aquifer (Arumugam, 1968). The annual WTF is 1-2 m (Arumugam, 1968). Data from several pumping tests were analysed using Hantush (1956) and Walton (1962), the vertical permeability is in the range of 0.003 to 0.07 m/day. Results from slug injection tests carried out on the unconfined sand aquifer indicate a low permeability typically in the range of 0.05 to 0.30 m/day (Lawrence and Dharmagunawardena, 1983).

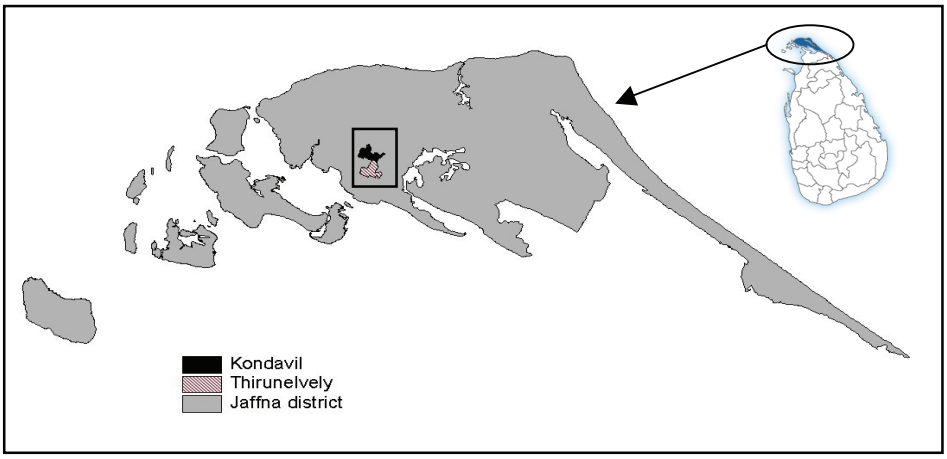

Figure 1. Location of the study in the Jaffna Peninsula

Methodology

Data for simulation

Data of year 2007 at Thirunelvely was considered for HYDRUS-1D simulation as this year has complete set of data including weather, crop, soil, and WTF needed for the numerical model simulation required by HYDRUS 1D for this paper. However the analysis was done for the complete cycle of two years.

Environmental parameters required for the estimation of potential evapotranspiration such as monthly average mean temperature, humidity, wind speed and sunshine hours were taken from the meteorological station, Jaffna.

Crop (Cabbage) data such as date of planting, full emergence of crop, duration of initial, development, mid and late stage, date of harvesting, root zone depth and soil data such as field capacity, permanent wilting point and bulk density recorded from the field in Thirunelvely were also used in this simulation (Mikunthan and De Silva 2009). Crop coefficients for required crops were taken from Allen *et al.* (1998). The selected cropping situation for simulation by HYDRUS-1D was unirrigated grassland with small trees and cabbage cultivated from mid March to late June. Grass was used in the model to represent the area when cabbage is not in the field.

Daily WTF data measured by using dip meters at twenty wells in Thirunelvely from January 2007 to December 2008 from a variety of sites across Thirunelvely were also used to compare the HYDRUS-1D simulated results.

Simulation of Potential Recharge using HYDRUS-1D

Numerical modelling of water flow

In this study, water flow and root zone moisture dynamics were simulated using HYDRUS-1D (Šimůnek *et al.*, 2005). HYDRUS-1D 3.0 is a Windows based modelling environment for water flow and solute transport analysis in variably saturated porous media. The base of this model is the variable saturated vertical soil domain where water flow is simulated. In HYDRUS, the root zone moisture dynamics are simulated with the Richard's equation assuming (i) that the soil is homogenous and isotropic, (ii) that the air phase does not affect the liquid flow processes, and (iii) the water flow due to thermal gradients is negligible. The governing equation for water flow is the 1D Richard's equation for unsaturated flow as follows:

$$\frac{d\theta(h)}{dt} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + 1\right)\right] - S(h) \qquad (1)$$

subject to the initial and boundary conditions chosen to implement

$$h(z,0) = ho(z) \tag{2}$$

$$-K(h)\left(\frac{\partial h}{\partial z} + 1\right)\Big|_{z\,=\,0} = qo(t) \tag{3}$$

$$\frac{dh}{dz}(L,t) = 0 \tag{4}$$

or

$$h(L,t) = h_L(t) \tag{5}$$

where:

h = soil water pressure head; θ= volumetric water content; t = time; z = vertical space coordinate assumed to be 0 at the soil surface and directed upward; K = unsaturated hydraulic conductivity; S = sink term to account for root water uptake; $h_0(z)$ is the initial condition; and $q_0(t)$ is the fluid flux across the soil surface boundary (Šimůnek *et al.*, 2005). This sink term is specified in terms of a potential uptake rate and stress factor (Feddes *et al.*, 1978) as follows:

$$S(h) = \propto (h) S_p \tag{6}$$

where S_p is the potential water uptake rate and α(h) is the dimensionless water stress response function (0 ≤ α ≤ 1) that prescribes the reduction in uptake that occurs due to drought stress. The functional form introduced by Feddes *et al.* (1978) was used for α(h). This function assumes h_1, h_2, h_3 and h_4 are threshold parameters such that uptake is at the potential rate when the pressure head is between h_2 and h_3. It drops off linearly when $h > h_2$ or $h < h_3$, and it becomes zero when $h < h_4$ or $h > h_1$. The crop specific default parameter values were taken from the database contained in HYDRUS-1D (Šimůnek *et al.*, 2005). The default parameters for grass used in this simulation were: h_1 = −10 cm, h_2 = -25 cm, h_{3l} = −200 cm, h_{3h} = −800 cm, h_4 = −8000

cm. The default parameters of Cabbage were: h_1 = −10 cm, h_2 = −25 cm, h_{3l}= − 600 cm, h_{3h}= −700cm, h_4= −8000 cm (Wesseling, 1991).

The surface boundary (Equation 3) was implemented as an atmospheric condition without surface ponding in which $q_0(t)$ equals rainfall minus potential evaporation as long as the pressure head determined at the soil surface exceeds some minimum negative value (-10000 cm in this study). It is assumed that surface runoff occurs when the surface becomes saturated, in which case $q_0(t)$ in Equation 3 decreases in value. The lower boundary condition is simulated as a free drainage condition (unit hydraulic gradient or constant head boundary at the bottom being appropriate due to the fact that the water table was far below the root zone (7-9 m below the root zone in the study area). Drainage from the bottom of the soil profile or bottom flux was assumed to be equal to the potential groundwater recharge.

Soil hydraulic properties

van Genuchten-Mualem's constitutive relationships were used to model the soil hydraulic properties (Mualem,1976; van Genuchten,1980).

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1+|\alpha h| \quad n] \quad 1-1/n} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \tag{7}$$

$$K(h) = K_s S_e^1 \left\{ \quad 1 - \left[1 - S_e^{n/(n-1)}\right] \quad 1-1/n \right\} \quad 2 \tag{8}$$

where: θ_r and θ_s are the residual and saturated water contents, respectively; α and n are empirical shape factors that depend on soil type; K_s is the saturated hydraulic conductivity; and S_e is the effective saturation. The latter is given by:

$$S_e = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} \tag{9}$$

Where: θ_s= saturated water content; θ_r= residual water content; α = air entry parameter; n= pore size distribution parameter; and l=pore connectivity parameter. The parameters α, n and l are empirical coefficients that determine the shape of the hydraulic functions. Running the model required specifying the hydraulic parameters θ_r, θ_s, α, n, K_s and l. HYDRUS-1D default parameter values for each of these parameters for sandy clay loam were used in this modelling initially. The default values for sandy clay loam were θ_r=0.1, θ_s=0.39, α=0.059, n=1.48, K_s=31.4 and l=0.5. All the units used in HYDRUS-1D were in cm and cm/day.

Evaporation and transpiration

In this study the Penman-Monteith equation (Allen *et al.*, 1998) was used to estimate the reference crop evapotranspiration rate, ET_o (mm/day). Potential evapotranspiration (ET_p) was calculated using the formula given by Allen *et al.* (1998):

$$ET_p(t) = K_c(t) \times ET_o(t) \quad (10)$$

where $ET_o(t)$ was discretized using daily time steps and $K_c(t)$ is a dimensionless crop coefficient that characterizes the plant water uptake and evaporation relative to the reference crop. The time variation of $K_c(t)$ in terms of annual crop growth is divided into the stages such as initial, crop development, mid season and late season. Allen *et al.* (1998) provide data on the length of growth stage and values of K_c for various crops. In this study the Allen *et al.* (1998) method and data to specify the crop and the values of K_c during each growth stage are used (Table 2). Then the potential evaporation rate of a soil under a standing crop was derived from the Pan Evaporation method (Meteorological Data, Colombo) and potential transpiration rates were calculated by subtracting evaporation from total ET.

The potential groundwater recharge simulated by HYDRUS-1D is compared with potential groundwater recharge estimated by modified soil moisture balance (MSMB) method (Mikunthan and De Silva, 2009) and water table fluctuation (WTF) method based on groundwater levels monitored in the study area. For the completeness of this paper these two methods (MSMB and WTF) are summarized below.

Estimation of Potential Recharge using Modified Soil Moisture Balance (MSMB) Method

The MSMB, a spreadsheet model was developed by Rushton (2003) and used in dry zone of Sri Lanka successfully (De Silva and Rushton, 2007). A daily estimate of the soil moisture balance is made with an input of rainfall minus run off and losses due to actual evapotranspiration and drainage, which may include aquifer recharge. Inputs and outputs for the soil moisture balance are shown schematically in Figure 3.

Features of modified soil moisture balance (MSMB) model are as follows:

- ***Runoff***

The main source of water is rainfall or irrigation. The actual infiltration of soil zone may be reduced due to interception or runoff. Runoff coefficient based on rainfall intensity and SMD were used in this model (Mikunthan and De Silva, 2009).

- ***Evapotranspiration***

The reference crop potential evapotranspiration ET_o can be estimated using the Penman-Monteith equation (Allen *et al.*, 1998). The FAO CROPWAT program (Smith, 1992), Version 5.6, was used to calculate the potential evapotranspiration for the study period. The crop water requirement differs according to type of crop, the date of planting, the stages of the crop and the date of harvesting which is determined by Kc the crop co-efficient. Crop stress is included using the concepts of total and readily available water. The reduced evapotranspiration depends on total and readily available evaporable water. As soil wetness decreases, the actual evapotranspiration begins to fall below the potential rate because the soil cannot supply water fast enough and/or because the roots can no longer extract water fast enough to meet the meteorological demand. Figure 4 shows how actual evapotranspiration is assumed to vary with SMD.

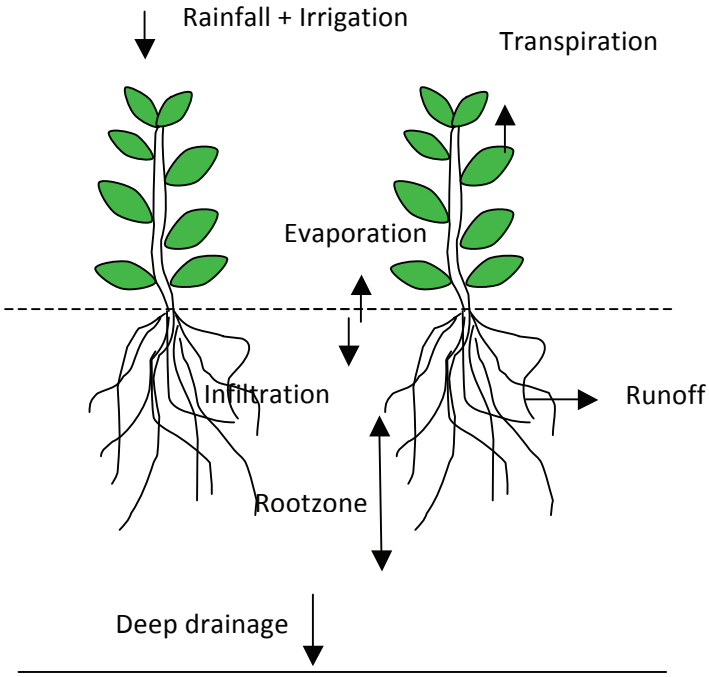

Figure 3. Diagram of soil water balance

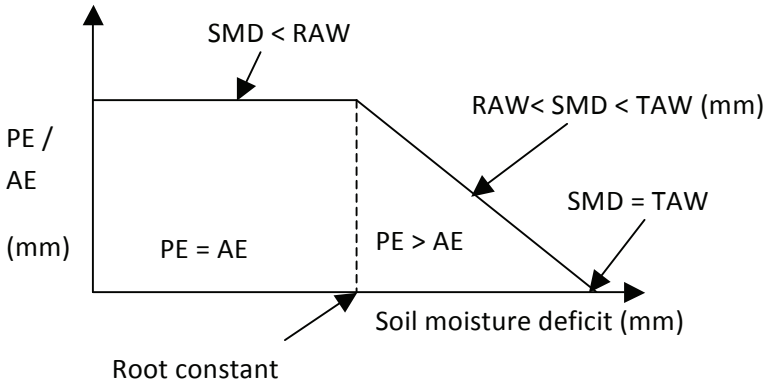

Figure 4. Situation of evaporation under different soil moisture deficits

The SMD on the start of the day, 1st January 2007, was taken as zero as it is more appropriate to consider after wet season rains.

The near surface soil storage (NSSS) reflects the idea that a certain percentage of soil moisture from rainfall or irrigation is retained for a short time near to the soil surface and might be used the next day. When a significant SMD exists and there is substantial rainfall, moisture is retained near the soil. The soil remains moist near the ground surface and crops continue to revive for several days after significant rainfall.

- ***Recharge***

Recharge will occur on days when the SMD is negative. As the SMD becomes zero the soil reaches field capacity and becomes free draining. Consequently recharge equals the quantity of water in excess of that required bringing the soil to FC.

Estimating Recharge using Water Table Fluctuation Method (WTF)

Healy and Cook (2002) stated that the water table fluctuation method may be the most widely used technique for recharge estimation in unconfined aquifers. The WTF approach is applicable to unconfined aquifers where WTF are caused solely by variations in net recharge or groundwater drainage. It is assumed that recharge over a period of interest is equal to the increase in water table elevation, after accounting for the groundwater recession that would have occurred during this period, multiplied by the specific yield. This is illustrated as follows:

$$R(t_j) = S_y \times \Delta H(t_j) \qquad (11)$$

in which

t_j -Time taken to reach the peak water table

$R(t_j)$ - Recharge occurring between times t_o (initial time) and t_j .

Sy - Specific yield and

$\Delta H(t_j)$ - The water table rise attributed to recharge .

$\Delta H(t_j)$ is estimated as the difference between the peak of a water level rise and the value of the extrapolated antecedent recession curve at the time of the peak. This recession curve is the trace that the well hydrograph would have followed if there had not been any precipitation. Predicting the recession curve is not always straightforward.

The data from the recovery phase of the single well pumping test was used to calculate specific yield of the aquifer by Slicnter recuperation method (Sirimanne and Vaidya, 1955). Specific yield of the limestone aquifer varied from 0.15 to 0.29 with the average value of 0.27 at Thirunelvely (Mikunthan and De Silva, 2009).

Results and Discussion

Soil Water Dynamics

Several parameter value combinations were considered while running HYDRUS-1D that varied from the soil hydraulic parameters, soil depth and root zone depth until the results of the HYDRUS-1D model simulations were similar to those of the MSMB and WTF methods. The following model out puts of HYDRUS-1D which had reasonable agreement were compared with the results obtained by MSMB and WTF methods and are explained in detail.

(i) Surface runoff
(ii) Soil Water Storage (SWS)/SMD
(iii) Bottom pressure head/ groundwater levels
(iv) Recharge

(i) Surface runoff

Surface runoff simulated by HYDRUS-1D was 35.7 cm for the year 2007 where the MSMB model gave 30.5 cm for the same period. When monthly values of runoff predicted by HYDRUS-1D were compared with those predicted by the MSMB model, there was a good agreement with R^2 = 0.91 (Figure 5) in 1:1 plot. Even the daily values of runoff showed good agreement, with R^2 = 0.8.

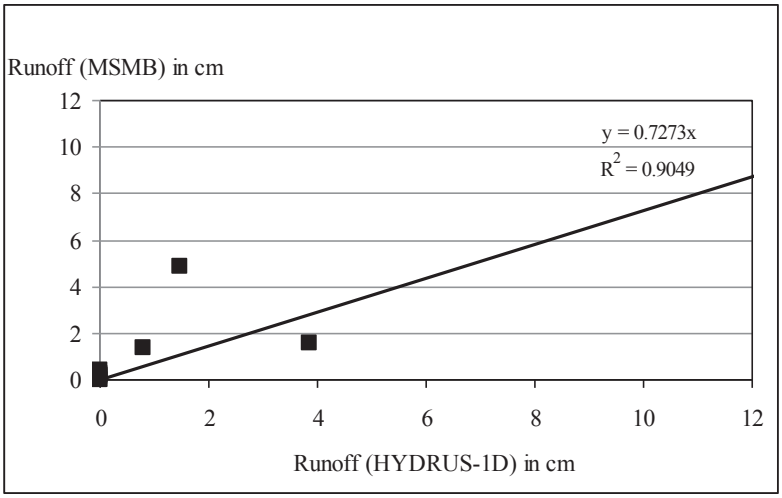

Figure 5. Relationship between the runoff simulated by HYDRUS 1D and MSMB models

(ii) SWS/SMD

SWS simulated by HYDRUS-1D and the SMD simulated by MSMB models are shown in Figure 6. Even though the approach used in the two models is fundamentally different, the model predictions follow a very similar pattern. The effect of differences in the initial conditions can be seen at the start of the year, but has decays rapidly so that by around mid-year the effect is no longer detectable. The linear correlation is good, with R^2= 0.88.

(iii) Bottom pressure head predicted by HYDRUS and groundwater levels observed in the field

Figure 7 shows the measured groundwater level fluctuation in the study area for a period of 2 years and 4 months from January 2007. Groundwater levels showed a cyclic seasonal variation during the years. Groundwater levels are deep in the study area varying from 7 to 10 m. Generally the groundwater recharge takes place from October to December/ January with wet season rains from early October. During this period the groundwater levels rise by up to 1.5 m to 2.0 m depending on the location. During the dry period from January to October the groundwater levels fall by about 0.5 m to 0.75 m due to the fact that there are surface storage tanks and other surface water sources around the study area to maintain this drop. Year 2007 was a normal year with an

annual rainfall of 1291 mm compared with other years, for example 2008, where the rainfall was higher than the average. The mean annual rainfall in the Jaffna Peninsula is approximately 1255 mm (Rajasooriyar *et al.*, 2002). In the years 2008 and 2009 the annual rainfall was higher than in 2007. During 2008 and 2009 there was a considerable amount of rainfall during April/May due to first inter-monsoon rainfall and it was possible that a small percentage of recharge to take place during that period (Figure 7).

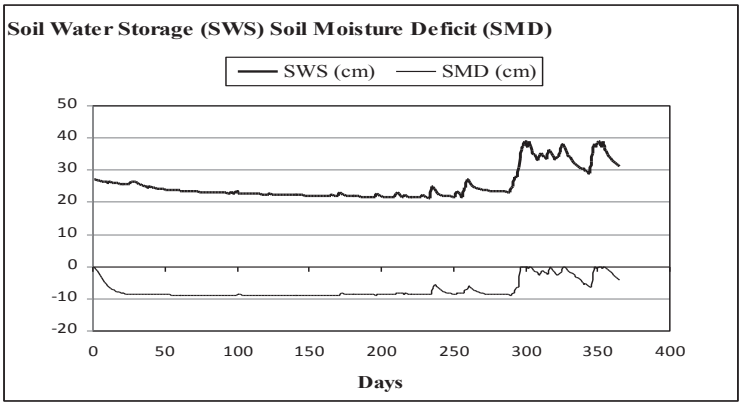

Figure 6. HYDRUS-1D simulated SWS and MSMB model Simulated SMD

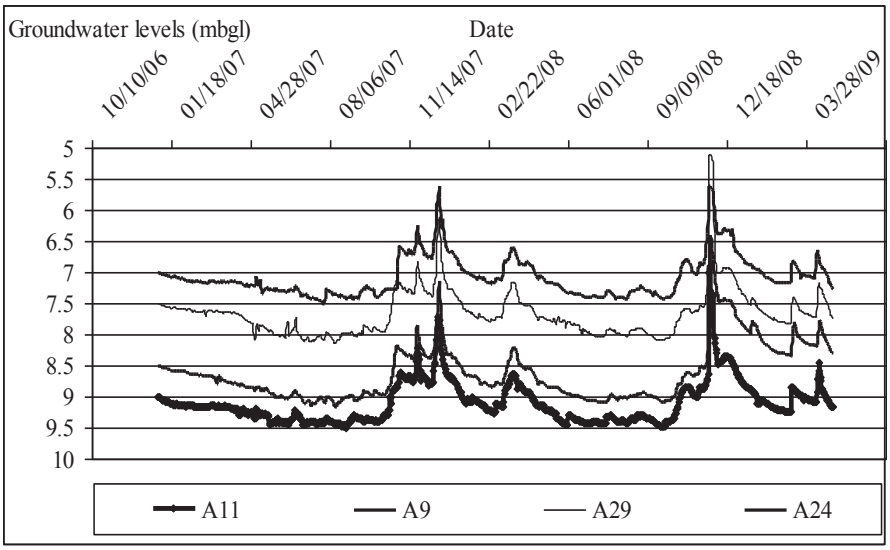

Figure 7. Observed WTF measured in meter below ground level in selected 4 wells in the study area

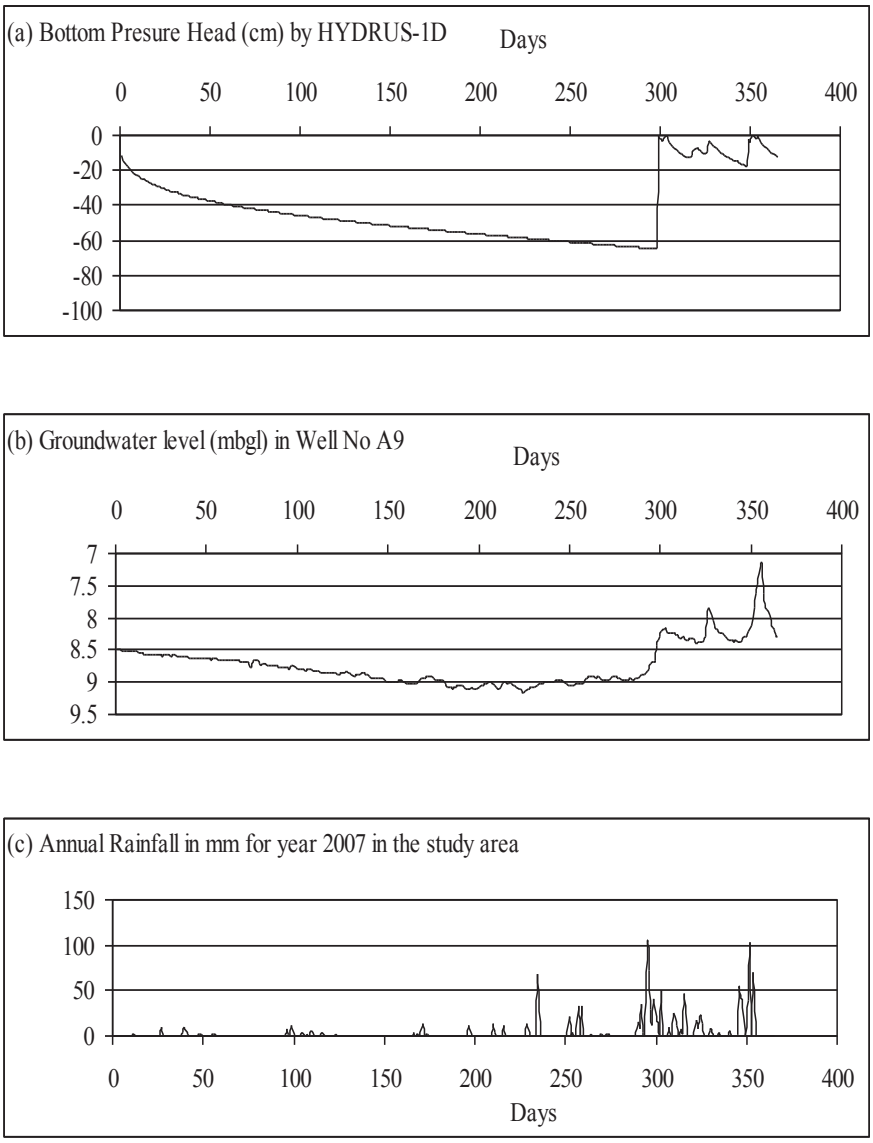

Figure 8. (a) HYDRUS-1D predicted bottom pressure head (cm) (b) WTF in Well no 9 (mbgl) (c) Rainfall in the study area

Figure 8(a) and (b) shows that the simulated bottom pressure head variation at 1 m depth soil using HYDRUS-1D closely agrees with the observed groundwater levels variation in the field at 8-9 m below ground level with a good coefficient of determination (R^2=0.83). The groundwater level drop of 0.50 - 0.75 m from January to October closely agreed with the simulated pressure

head drop. Further, the groundwater levels started to rise with wet season rains from mid October 2007 (Figure 8 c) and HYDRUS-1D too predicted the rise on during the same period.

(iv) Recharge

In HYDRUS-1D, when the SWS is the maximum and no more water can be stored in the root zone, drainage will occur to the groundwater (bottom flux). The HYDRUS-1D simulated potential groundwater recharge was 41.8 cm per year. This is 30-35 percent of the annual rainfall, in agreement with the estimates of Rajasooriyar *et al.* (2002) for the study area. The recharge calculated by the WTF method based on measured groundwater levels was 29.8 cm. But the MSMB model estimated recharge was 35.0 mm (Mikunthan and De Silva, 2009). However, as shown in Figure 9, the HYDRUS-1D results have a higher coefficient of determination (R^2 = 0.95) with the WTF method results than they do with the MSMB model results in (R^2 = 0.91) in 1:1 plots.

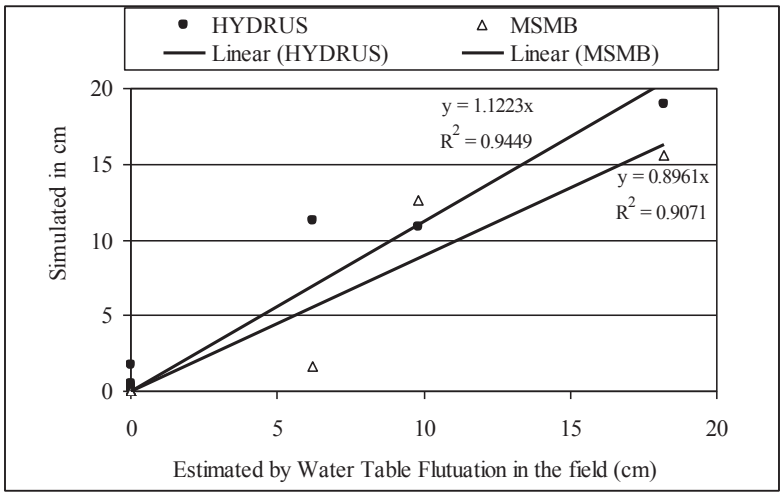

Figure 9. Relationship between the recharge estimated by the water table fluctuation method and that simulated with the HYDRUS-1D and MSMB models

In the HYDRUS-1D simulation root zone of 1 m is only considered. Similarly in the MSMB also the soil moisture balance is carried out only for the 1 m root zone. Recharge estimated with MSMB and that simulated using HYDRUS-1D for the same study conditions are more or less same with certain percentage of error. But when compared with measured groundwater fluctuation at

the depth of 7-8 m in the study areas HYDRUS-1D seems to overestimated the recharge which could be justified as HYDRUS-1D deals with only 1 m root zone.

Overall, good agreement was achieved between recharge calculated using field measurements on groundwater fluctuations, estimated by MSMB and HYDRUS-1D predictions. Compared with the methods available for recharge calculation, HYDRUS-1D the numerical simulation is a far more convenient and cost effective approach.

Sensitivity Assessment

The root zone modelling methodology adopted in HYDRUS-1D is crucial for calculating recharge in arid and semi-arid regions where evapotranspiration may drop below potential rates. Several potential sources of uncertainty exist, however, in the vadose zone modelling approach used in this study. Possible sources of uncertainty include the values of several model parameters needed to run HYDRUS-1D, including soil hydraulic parameters, crop coefficient and drought stress parameters in the uptake model of Feddes *et al.* (1978). However, to minimise the error, sensitivity analysis was done with several model parameters. The simulations showed that the most important parameters for groundwater recharge were the soil hydraulic parameters. Amongst the soil hydraulic parameters (n, θ_s, K_s, α and θ_r) residual water content was found to be the least sensitive, which agrees with Jimenez-Martinez *et al.* (2009). Compared with the other parameters, K_s was the most sensitive: for example, an increase or decrease by 50% causes ±15-20% in recharge rates. Lower values of K_s, such as might be the case for finer textured soils, leads to a lower recharge rate due to more runoff. However, the accurate characterization of the prediction uncertainty is problematic because of a lack of knowledge about parameter variability and parameter correlation structure.

Limitations of Recharge Estimation Methods

The MSMB used in this study is a simple spreadsheet model which has less flexibility. For the MSMB, the main limitation is that it relies on the subtraction of large quantities (ET and P) to estimate a small quantity (recharge). The uncertainty associated to estimate thus greatly depends on the relative magnitude of these inputs. The availability of a data set covering a longer period

would also have helped to reduce uncertainty in recharge estimates. The other source of error identified relates to the estimation of MSMB inputs in this study for which measured data were unavailable due to the situation prevailed in the study area. Therefore extra time and funds were used to check the validity of the data to make it reliable and relevant before using for this study. Evapotranspiration was estimated with a recognized method for which measured inputs (e.g. wind, relative humidity) were available. However, run-off, which was approximated with a constant coefficient, could represent a significant source of error. Reliable and complete run-off data sets for a few gauging stations would ideally be required in order to obtain more accurate run-off estimates. Therefore using MSMB for recharge estimation is a tedious and an expensive process.

Data collection and monitoring groundwater levels are expensive and difficult to manage in developing countries especially in the areas such as the study area in this paper where research or any sort of continuous monitoring of groundwater levels has not been taken place except isolated studies for the last 30 years due to the ethnic conflict. The WTF method needs continuous monitoring of groundwater levels which was not available in the study area and the continuous monitoring of groundwater levels is expensive. Therefore in this study groundwater levels were monitored in the wells in the study area carefully using a trained person as installing piezo meters will cause additional financial burden for the research study.

Further, there were no estimated specific yield values for the area study area as the recharge was calculated by multiplying the rise and fall of groundwater levels by specific yield. Therefore pumping tests were conducted and the specific yield value was estimated. Therefore depending on WTF method for recharge estimation is also fairly expensive and a tedious procedure.

This study has shown that HYDRUS-1D which is a numerical model is having good agreement with MSMB and WTF method even though these methods are different in its principles. Therefore HYDRUS-1D is fairly reliable method to use for recharge estimation instead of MSMB and WTF methods with an additional advantage of having solute transport facility.

Conclusions

In the dry zone of Sri Lanka, accurate knowledge of groundwater recharge is important for sustainable water resources management. In this study groundwater recharge was simulated with HYDRUS-1D using root zone modelling approach with rainfall, evapotranspiration and soil moisture dynamics for grass with cabbage from mid March till late May for the year 2007 in the Jaffna Peninsula, northern Sri Lanka. HYDRUS-1D was found to be a very useful tool for simulating potential groundwater recharge when actual field data are limited. Good agreement on potential groundwater recharge was achieved between HYDRUS-1D simulations, MSMB results and estimates using WTF method based on the field observed groundwater levels. HYDRUS-1D produced 41.8 cm of recharge whereas as the previously used MSMB estimated 35.0 cm. Recharge calculated using WTF method in this study is 29.8 cm. Even though HYDRUS-1D seems to overestimate it may not be the case as the HYDRUS-1D simulate 1 m root zone and the coefficient of determination (R^2) between measured and predicted groundwater recharge for individual events was 0.95 for the water level fluctuation method and 0.91 for that with MSMB.

Further, HYDRUS-1D is used for solute transport, for example in predicting groundwater pollution due to nitrogen fertilizer application which cannot be achieved by MSMB model (De Silva and Tellam, 2011). Now that it has been demonstrated that HYDRUS-1D adequately reproduces the water fluxes predicted by other methods, it can be used with more confidence to investigate groundwater recharge and pollution issues.

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Dielectric Properties of Composite Films Made from Tin(IV) Oxide and Magnesium Oxide

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Abstract

Impedance spectroscopy (IS) subsumes the small signal measurement of the linear electrical response of a material of interest including electrode effects and the subsequent analysis of the response to yield useful information about physicochemical properties of the systems. In the majority of cases, the nano-structured films are better represented by a more complicated network of resistances and capacitances, so-called equivalent circuit. IS analysis generally makes a considerable use of these equivalent circuits.

Films made from SnO_2 and MgO have been taken into consideration and analyzed using IS to find the dielectric properties. Analyzing the Nyquist plots, the sheet resistance of the CTO glass was found to be around 610 Ω. But the parallel resistance of the film varied dramatically while altering the composition.

10% of MgO in the SnO_2/MgO composite showed a high impedance which is in two orders of magnitude higher than pure MgO. This is due to the confinement of electrons in quantum well structure formed by layer of MgO around SnO_2 particles. The dielectric loss is also found to be minimal at this composition. The variation of real and imaginary parts of permittivity of the composite films of SnO_2 and MgO are being discussed for different compositions in this study. SnO_2 and MgO composite films of 10% MgO could find applications in devices such as capacitors and thin film transistors to be used as a novel dielectric.

Introduction

Small signal measurement of linear electrical response of a material including electrode effects and the subsequent analysis are considered in impedance spectroscopy (IS) to yield useful information about physicochemical properties of the systems of interest (Macdonald, 1992). Furthermore, the response due to the

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different processes is recorded in a single frequency sweep, according to various frequencies existing in the system. This technique is widely used due to its sensitivity and its ability to separate the different processes involved in the materials and devices (Bisquert, 2002). However impedance analysis of systems requires consideration of additional aspects such as resistance, capacitance and loss tangent of materials to extract the available information and characterize the dielectric properties.

In the majority of cases, the nano-structured films are better represented by a more complicated network of resistances and capacitances, so-called equivalent circuit. IS analysis generally makes a considerable use of equivalent circuits and shows a more complex behavior depending on the frequency range used in the complex impedance analysis.

Physical characteristics including the dielectric properties dramatically change in composite materials rather than in the individual constituent. Therefore, in this study, composite porous films made of SnO_2 and MgO have been taken into account and the characteristics of these films were analyzed using IS to describe the variation of dielectric properties of different compositions.

Methodology

Series of nanocrystalline SnO_2 and MgO composite films with area 1 cm^2 were prepared by different mass percentages keeping the total mass at 0.5 g. Films of thickness 10 μm (estimated gravimetrically) were prepared using doctor blade method on conducting tin oxide (CTO) glass plates (15 Ωcm^{-2}) which was made by grinding SnO_2 and MgO powder (Aldrich) 15 minutes with 1 ml of acetic acid and two drops of Triton X-100 in ethyl alcohol. These films were sintered at 450 ^{0}C in a furnace for 30 minutes.

Complex plane impedance spectra of these films were measured by Solartron 1260 frequency response analyser using SMART software which is provided with the instrument. A sweep was carried out for different mass percentages of SnO_2 and MgO films coated on CTO glass with Pt sputtered glass plate as the counter electrode by setting AC level at 100 mV in the frequency range from 1 MHz to 1 Hz while measuring the impedance in 1.0 s integrations.

Results and Discussion

A characteristic semicircle Nyquist plots (where real impedance is plotted against the imaginary impedance) were observed for all of the SnO_2 and MgO composite films. Composite SnO_2 and MgO films deposited on CTO glass model a cell where the sheet resistance (Z_1) of the CTO glass is in series with the parallel combination of capacitance and resistance of the composite film (Z_2). (Figure 1)

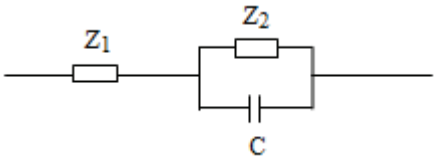

Figure 1. Equivalent circuit for MgO and SnO_2 composite films

It was noted that Z_1 value did not vary significantly in all the compositions because it represents the sheet resistance of the CTO glass which was found to be around 610 Ω. But Z_2 value which is the parallel resistance of the film varied dramatically while altering the composition (Figure 2).

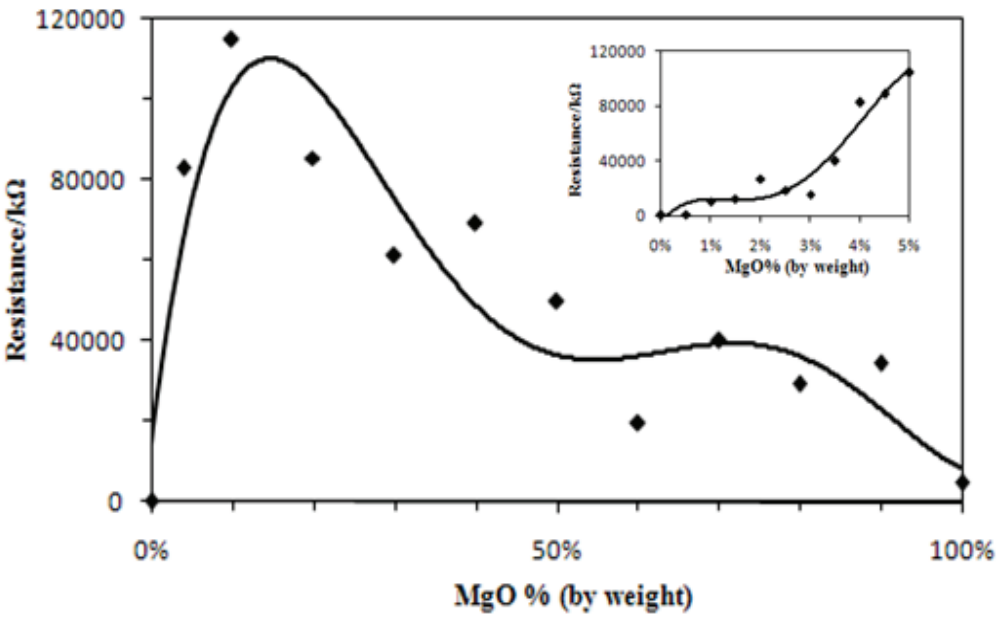

Figure 2. Variation of the resistance vs MgO % (by weight) of SnO_2/MgO composite films

As evident from insertion of Figure 2, dramatic increment of the resistance in the composite film initially observed up to 10% of MgO in the composite film. This value is in two orders of magnitude higher than the resistance of 100% MgO film of the same thickness. Further addition of MgO to the composite decreased the resistance of the film rapidly and remains nearly constant from 40% to 80% of MgO in the film. Again after 80%, resistance reduces further until 100% of MgO is reached.

This behaviour of the SnO_2 and MgO composite film could be explained considering the band structure of SnO_2 and MgO. Figure 3 depicts the energy positions of conduction band and valence band of SnO_2 and MgO. The band gap of SnO_2 is ~ 3.8 eV and it is 7.8 eV for MgO. SnO_2 and MgO make a type 1 hetero-structure at the interface as can be seen from the band diagram. According to the experimental procedure some of the MgO added to the paste dissolve in acetic acid as magnesium acetate and MgO is formed again at the sintering of the film at 450 ^{0}C around SnO_2 particles.

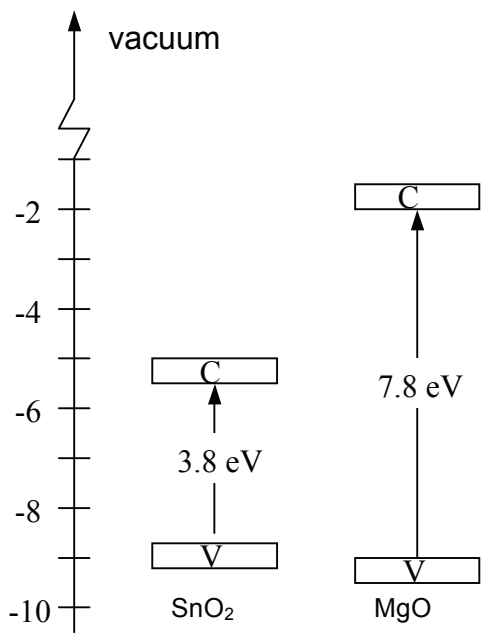

Figure 3. Energy level diagram of SnO_2 and MgO

At low percentages of MgO the thickness of the MgO shell formed around the SnO_2 particles can be calculated from the formula

$T = \frac{r}{3} \times \frac{W_S \ \rho_S}{W_C \ \rho_C}$ where W_S - weight of shell material, W_C - weight of core material, ρ_s - density of shell material and ρ_c - density of core material. The particle size of SnO_2 is known to be around 200 nm from SEM measurement. Substituting the density of SnO_2 (6.95 x 10^3 kg m^{-3}) and MgO (3.58 x 10^3 kg m^{-3}) in the above formula, thickness of the MgO shell at different percentages of MgO was calculated and is given in Table 1.

Table 1. Thickness of MgO shell on SnO_2 particles at different MgO %

MgO%	1%	2%	3%	5%	10%
T (nm)	0.2	0.4	0.5	1.0	2.0

When the percentage of MgO is less than 3% (T < 0.5 nm) the resistance of the film is only slightly higher than the pure SnO_2 film. This can be clearly seen in the inset of Figure 2. At this thickness of the MgO shell (<0.5 nm) electrons can tunnel across it when an ac signal is applied. So, that the resistance of the film is considerably low (Figure 4a). But when the MgO percentage is further increased (~10%) the composite structure becomes more like a multiple quantum well structure where electrons in SnO_2 particles have to traverse to the subsequent SnO_2 particle across deep trap states of MgO following a trapping and detrapping mechanism (Figure 4b).

It can be found in the literature that MgO has trap states at 1.8 eV, 2.4 eV and 3.2 eV below the conduction band measured by UV/visible reflectance spectroscopy (Berger *et al.*, 2004). When the MgO percentage is further increased the electron transport merely takes place across the shallow traps of MgO, so that the resistance of the film is reduced again because now the electrons confined in SnO_2 particles of quantum well structure have disappeared (Figure 4c).

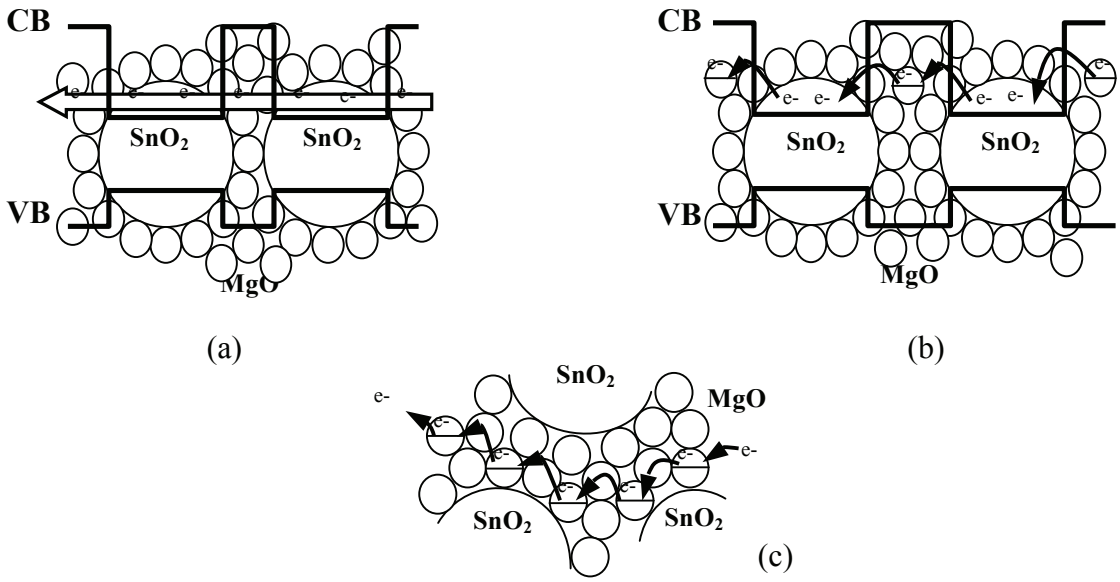

Figure 4. Mechanisms of electron transport in SnO_2/MgO composite at different MgO% (a) MgO< 3% (b) MgO~10% (c) MgO> 40%

Since we have carried out the impedance spectroscopic measurements on SnO_2 and MgO composite films as a parallel plate capacitor, the capacitance, *C* and loss tangent, *tan δ* were measured for different compositions of the films to find out the real and imaginary parts of permittivity. The relative complex permittivity, ε^* relate to the real permittivity ε and imaginary permittivity $\acute{\varepsilon}$ as,

$\varepsilon^* = \varepsilon - j\varepsilon^{/}$ where, $j = \sqrt{-1}$.

The real (ε) and imaginary ($\acute{\varepsilon}$) part of permittivity can be calculated from the measured capacitance and loss tangent as,

$$\varepsilon = \frac{Cd}{\varepsilon_0 A} \text{ and } \varepsilon^{/} = \varepsilon \tan\delta,$$ where *d* is the thickness of the

film, *A* area of the film and ε_o is permittivity of free space (ε_o = 8.85 x 10^{-12} $C^2N^{-1}m^{-2}$).

Figure 5 shows the variation of real part of permittivity with MgO % in the composite films of SnO_2 and MgO. Similar to the variation of film resistance, the real part of the permittivity also got the highest value at 10% of MgO in the composite films. The insertion of Figure 5 is the variation of capacitance of the films at different compositions which follows the same pattern.

The imaginary part of the permittivity of the composite films is depicted in Figure 6. It is noticeable that the $\acute{\varepsilon}$ has lower value at 10% of MgO in the composite film. The imaginary part of permittivity is responsible for the dielectric losses.

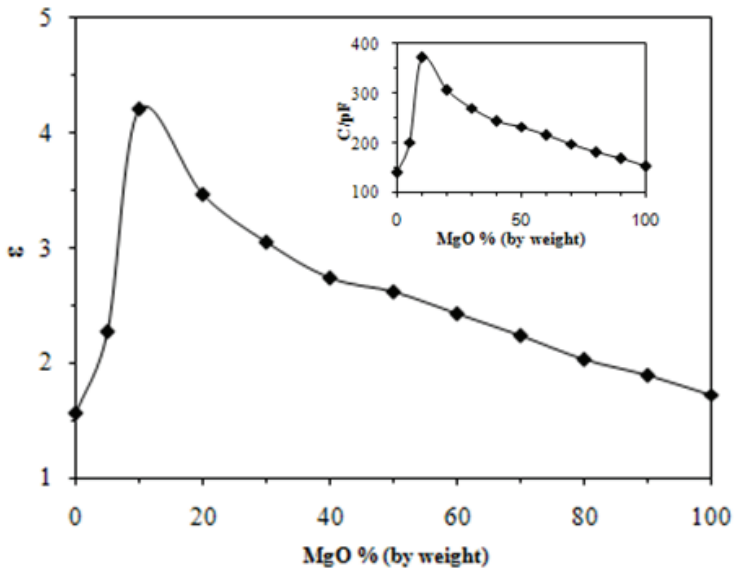

Figure 5. Variation of real part of permittivity (ε) with MgO %

Therefore the dielectric loss has a minimum at 10% MgO which lies in between the dielectric losses of SnO_2 and MgO.

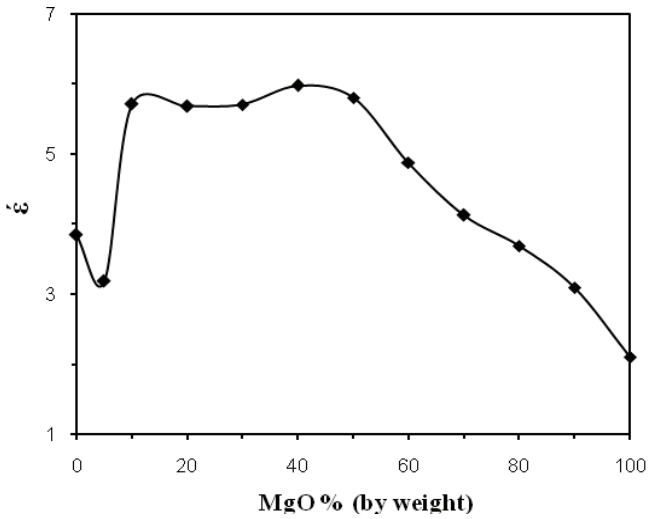

Figure 6. Variation of imaginary part of permittivity (*έ*) with MgO%

Figure 7 compares the dielectric loss of pure SnO_2, MgO and composite film of 10% MgO at different frequencies. Flattening the curves after 10 Hz, the composite film of 10% of MgO has the lowest dielectric loss. This observation further verifies the behaviour of *έ* of the composite at 10% of MgO.

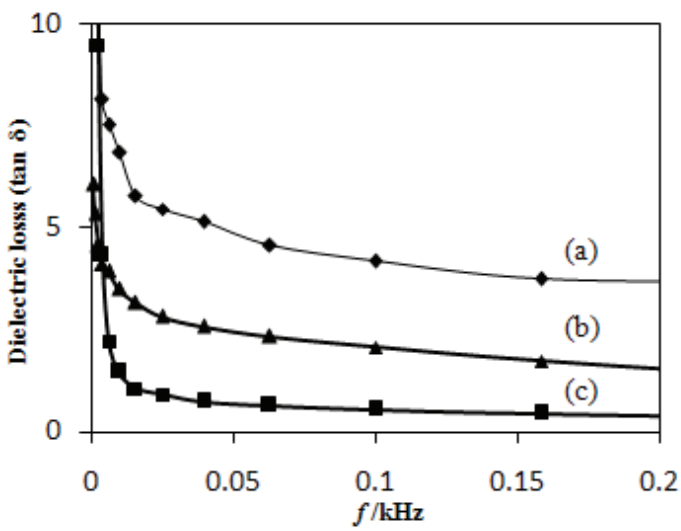

Figure 7. Dielectric losses of (a) SnO_2 (b) MgO and (c) SnO_2 and MgO film with 10% of MgO

Conclusion

The resistance and capacitance of composite films made of SnO_2 and MgO were measured by impedance spectroscopy. The real and imaginary parts of the permittivity of the composites were calculated measuring capacitance and loss tangent. Addition of 10% MgO to the composite showed a high impedance which is in two orders of magnitude higher than pure MgO. This can be explained by electron confinement in quantum well structures formed due to MgO thin shell around SnO_2 particles. The loss tangent is also found to be minimal at this composition. Therefore, 10% of MgO in the SnO_2 and MgO composite could be applicable in devices such as capacitors and thin film transistors to function as a good dielectric material.

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Overhead Pedestrian Crossings – Economic Evaluation through Vehicle Operating Cost and Travel Time Savings

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Abstract:

At-grade road crossing facility presently available at the main entrance to the Sri Lanka Institute of Information Technology (SLIIT) Malabe can be improved as a solution to minimize the disturbance of traffic flow along Malabe - Kaduwela road. It is observed that a large number of students cross the road throughout the day, especially during the peak of traffic. Several other reasons for this traffic congestion were identified, such as; unruliness of pedestrians, violation of traffic rules by drivers (especially bus drivers who stop buses everywhere although there are properly located bus stops), inadequate road width etc. Due to the above reasons, vehicles traveling along this stretch of road have to constantly slow down and then regain their original speed after passing the location. Introduction of an overhead pedestrians' crossing at the location would separate pedestrians from traffic to minimize the vehicle - pedestrian conflict to create a uniform traffic flow along the road section. Hence, by minimizing the sudden speed variation of vehicles (speed change cycle) due to the existing pedestrians crossing the road, the additional Vehicle Operating Cost (VOC), additional travel time and risk for pedestrians when crossing the road, as well as uncomfortable driving condition for drivers can be reduced.

The objective of this study is to minimize the additional VOC and travel time due to sudden speed variation at this existing pedestrian crossing by improving the traffic flow condition. Therefore, an overhead pedestrian crossing with the view of facilitating the pedestrians to cross the road comfortably and safely is proposed. The proposed structure has a clear height of 5.5 m and 18 m of span. Two flights of steps of one meter width were designed for both ends of the overhead bridge as access.

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Total cost for the proposed structure was computed for the year of 2012. Further the additional cost for the VOC and travel time per day were analyzed and predicted for a period of 20 years from the year 2012. After having determined the costs and benefits of the project, a method was evolved for relating these two so as to arrive at the assessment of the viability of the project in economic terms. Among a number of methods developed for such an economic evaluation, Internal Rate of Return (IRR) method was justified and selected.

Keywords: Overhead Pedestrian Crossings, Vehicle Operating Costs, Speed Change Cycles

Introduction

When a vehicle travels at its cruise speed, if the speed is interrupted due to change of road geometry, road features or any road event (such as lane reductions, presence of road intersections, interruptions due to pedestrian crossings etc.), it decelerates to a minimum speed (which can be even a complete stop). Subsequently, the vehicle has to accelerate back to its original cruise speed. A vehicle undergoes a speed change cycle which is the difference in travel time and Vehicle Operating Cost (VOC) for traveling the distance of the speed cycle at the original cruise speed versus reduction of speed through the speed cycle.

The Malabe - Kaduwela road with an Average Daily Traffic (ADT) of 39,800 vehicles per day in front of Malabe Campus of the Sri Lanka Institute of Information Technology (SLIIT) was selected as the study location.

At this location, traffic flow is constantly obstructed by the existing pedestrian crossing at the entrance of the Malabe Campus of SLIIT. This stretch of road is straight with minimum disturbance to traffic except for heavy pedestrian crossing taking place at the location. Because of this very high ADT, of 39,800 reductions and regaining the speed of vehicles cause additional VOC, increase travel time, higher accident risk, increase in vehicular emissions, and additional cost to the national economy may result.

Figure 1. Location of the study

Hence, one can quantify the additional cost for more fuel and oil consumption, wastage of tires, wear and tear of mechanical parts, additional travel time etc. As a solution, to separate the pedestrian and vehicular movement, a safe overhead pedestrian crossing structure is proposed. The construction cost is compared with the savings from reduction in travel time and VOC, and then construction of the structure is justified by carrying out a cost/benefit analysis.

Aim and Objectives

The aim of this project is to quantify the value of additional burden to economy due to the speed change of a vehicle at the existing crossing; predict it for future time periods. This also attempts to reveal how long it will take to recover the construction cost if an overhead crossing is introduced to the main entrance of SLIIT, instead of the existing ground level crossing. To achieve the above aim, the following objectives

had to be achieved. This study will justify and design an overhead pedestrian crossing at the main entrance to SLIIT, for reduced speed variation of traffic and safe movement of vehicular and pedestrian traffic by paying attention to the following:

- Quantify the additional vehicle operating cost and additional travel time and predict it for the future time periods.
- Forecast the number of pedestrians, crossing at the location after 20 years.
- Estimate the construction cost of the overhead pedestrian crossing and compare it with the saving on additional burden on economy to calculate the recovery period of construction cost.

In addition to the above objectives, there are some interim objectives that should be satisfied.

1. To check whether the road capacity of Malabe – Kaduwela road is adequate to cater to the current traffic volume.
2. Design the Malabe – Kaduwela road for year 2032 with a suitable level of service to cater to forecasted traffic volume.
3. Design of overhead pedestrian crossing to suit the pedestrian activities in this area and with an acceptable level of service to cater to forecasted pedestrian volume for year 2032.

Methodology

Step 1: Traffic survey

Firstly, traffic flow pattern and pedestrian crossing pattern around the study area were measured. Vehicles were counted manually on both directions at 15-minute intervals on a week day. Two directional vehicular flows for 24 hours are as shown in Figure 2. Peak hours were identified as; morning peak is 7:00 to 8:00 a.m., mid-day peak is 1:00 to 2:00 p.m. and evening peak is 5:00 to 6:00 p.m.

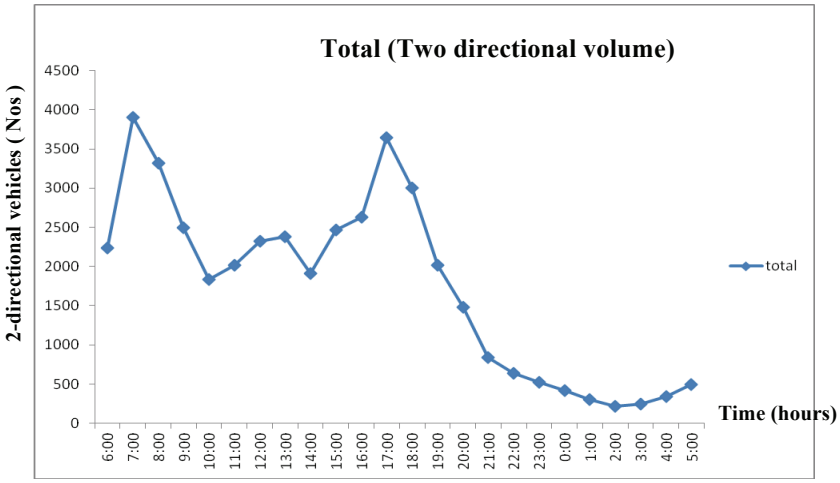

Figure 2. 24 hour vehicle distribution

Step 2: Pedestrian survey

A pedestrian count at the entrance to the SLIIT was done for 5-minute intervals throughout the day, in order to identify the pedestrian peak hours. Two directional pedestrian crossing flows is as shown in Figure 3. Pedestrian crossing peaks were identified as; morning peak from 7:45 to 8:45 a.m., mid-day peak from 12:45 to 1:45 p.m. and evening peak from 4:55 to 5:55 p.m. on a week day.

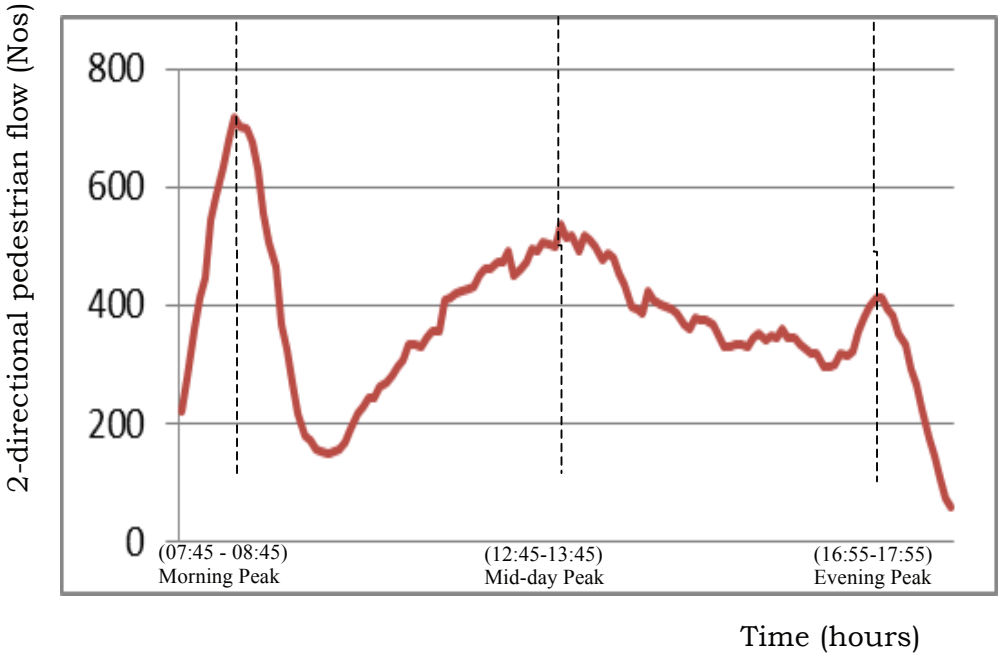

Figure 3. Two directional pedestrian crossing flow

Step 3: Traffic volume study

As per two directional traffic volume, 7 time slots were selected to carry out the speed profile study as indicated in Figure 4. The study analysis was carried-out under following assumptions. It was assumed that vehicular flow pattern and vehicle composition at the study location is the same all 7 days through the year. It was also assumed that flow pattern changes due to weather changes and the peak hours will not vary. Seasonal variation of traffic at the study location has been ignored.

To generate average speed profiles the time slots were taken as follows (Figure 4):

Slot 1	-	6.00 a.m.	-	8.00 a.m.	
Slot 2	-	8.00 a.m.	-	9.00 a.m.	
Slot 3	-	9.00 a.m.	-	12.00 noon	& 1.30 p.m. - 3.30 p.m.
Slot 4	-	12.00 noon	-	3.30 p.m.	
Slot 5	-	3.30 p.m.	-	6.30 p.m.	
Slot 6	-	6.30 p.m.	-	10.00 p.m.	
Slot 7	-	10.00 p.m.	-	6.00 a.m.	

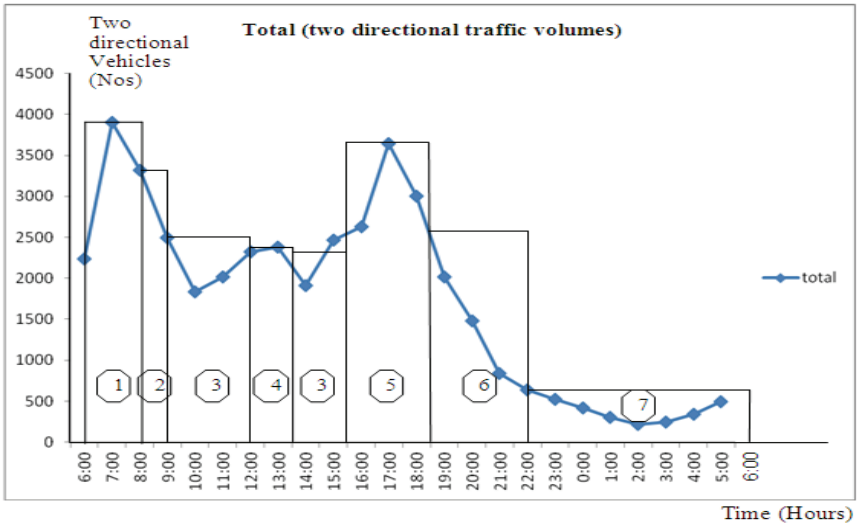

Figure 4. Two directional traffic volumes and different time slots

Step 4: Speed measurements

As shown in Figure 5, either sides of the existing pedestrian crossing were divided into 10 m sections to take speed measurements. Speeds of random 25 vehicles (including all vehicle categories) were measured in every 10 meter road segment. In addition, average speed was measured 100 meters away from the pedestrian crossing along both sides. Average speed variation for all categories of vehicles during each time slot (for both directions) was recorded and corresponding speed profiles for each time were drawn.

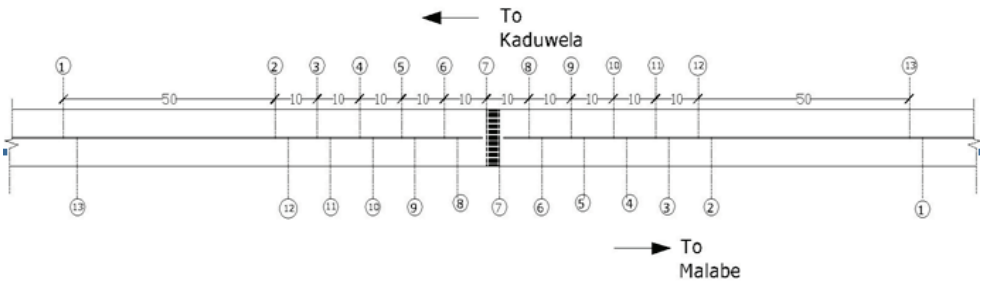

Figure 5. Speed measurement locations

Speed Profiles

Table 1 and Figure 6 indicate the average speed profile for time slot 1 (i.e. 6.00 a.m. - 8.00 a.m. from Malabe to Kaduwela direction). Similarly, average speed profiles of both travel directions for all 7 time slots were plotted.

Table 1. Speed variation of traffic during morning peak hour

Speed Variation in 06:00 – 08:00													
Section	1	2	3	4	5	6	7	8	9	10	11	12	13
Distance	-100	-50	-40	-30	-20	-10	0	+10	+20	+30	+40	+50	+100
Speed	47	47	46	33	29	21	13	21	26	29	37	47	47

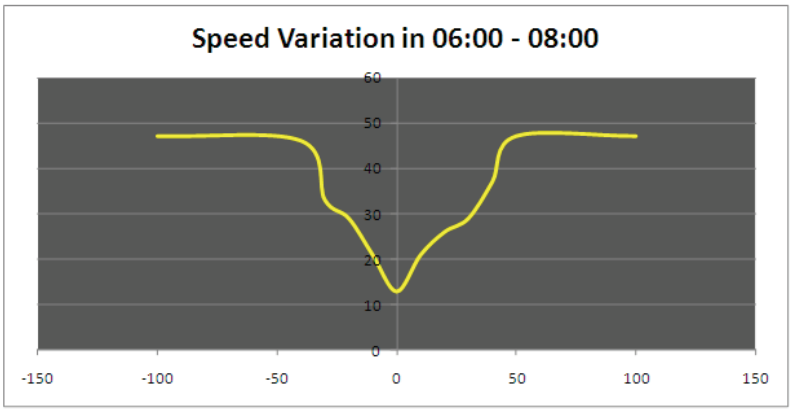

Figure 6. Average speed profile for time slot 1 (6.00 a.m. - 8.00 a.m. from Malabe to Kaduwela)

Step 5: Determination of additional vehicle operating cost (VOC) and additional travel time for a speed change cycle

The additional vehicle operating cost for speed change cycles of each vehicle category was computed by using the VOC tables obtained from NZ Transport Agency's Economic Evaluation. Within the selected time slots additional VOC for each vehicle class was computed for both directions. Hence,

the total additional VOC values per day (due to speed change cycle) for all classes were computed separately.

The additional travel time for a speed change cycle is the difference in travel time for traveling the distance of the speed cycle at the original cruise speed versus reduced speed through the speed cycle. The road user values are used to produce travel time values for uncongested and congested traffic conditions. Hence with the help of speed change cycles, savings on VOC and travel time were computed on annual basis due to the construction of the overhead pedestrian crossing.

Step 6: Design of the overhead pedestrian crossing

Based on the pedestrian counts and opinion survey results, the overhead pedestrian crossing structure was designed at the location for minimum pedestrian/traffic conflict. The span of the structure was decided based on the designed carriageway width of the road for a projected traffic for 20 years from present. The width of the structure was determined according to the forecasted pedestrian volume after the same period of time for a LOS of C (Highway Capacity Manual, 1985). Vertical clearance was decided based on RDA standards (RDA, 1998). Design of the structure was done as a combination of pre-stressed and reinforced concrete. Details of structural designs of the study are not indicated in this publication.

Step 7: Cost estimation

As described in step 5, the total additional VOC per a typical day for all vehicle classes as they undergo a speed change cycle due to the existing pedestrian crossing was computed. At the same time, for the same speed change cycle, additional travel time per day for all vehicle classes was determined (NZ Transport Agency). The total cost for additional travel time for all vehicles classes was calculated by considering the annual income of different road users. The total cost for additional travel time, the total cost for fuel and oil wastage, total cost for tire wastages, total cost for maintenance and repairs, total cost for depreciation per day were also computed. It can also be predicted for future time periods by taking in to account the traffic growth rate in

Colombo district.

The construction cost of the overhead pedestrian crossing was computed separately.

Step 8: Economic evaluation

By comparing the various methods available for economic evaluation, Internal Rate of Return (IRR) method was selected for economic evaluation of this study. The IRR is the discount rate, which makes the discounted future benefits equal to the initial outlay. In other words, it is the discount rate, which makes the stream of cash flow to zero.

Data Analysis

1. The traffic volume forecast

Traffic volume forecast for future time periods is required for designing of road width and additional lanes to be provided after 20 years. Afterwards, designed road width is required to determine the effective span of the over passes. Road width and number of lanes to be provided is determined according to US highway capacity manual 1985. By considering parameters such as present traffic volume, vehicle categories, per capita income, traffic growth rate, number of by-roads, number of junction and round about etc. RDA has developed a system to predict the average number of vehicles for a typical day of a forthcoming year on each road section governed by RDA in the Colombo area. Traffic data was collected from RDA to find the traffic growth of selected road section.

2. Pedestrians' volume forecast

Pedestrians' volume forecast for a future time period is required for designing the width of the over pass after 20 years. According to the data of Census and Statistics Department, the average annual population growth rate of Colombo district is 1.4% *(Department Census and Statistics).*

3. Additional vehicles operating cost (VOC)

Every vehicle around the existing pedestrian crossings undergoes speed reduction and re-gaining back to the initial speed (speed change cycle) as shown in Figure 7. The additional vehicle operating cost for a speed change cycle of

each vehicle category can be taken by using the vehicle operating cost tables. Within the selected time slots, additional VOC for each vehicle class can be found for both directions. Now the total additional VOC value per day (due to speed change cycle) for all classes can be estimated. But NZ Transport Agency's Economic Evaluation Manual does not include motorcycles and 3-wheelers, which are widely used in Sri Lanka. VOC for these vehicle types, therefore, are estimated relative to the cost of operating cars, using the factors listed in the Table 2.

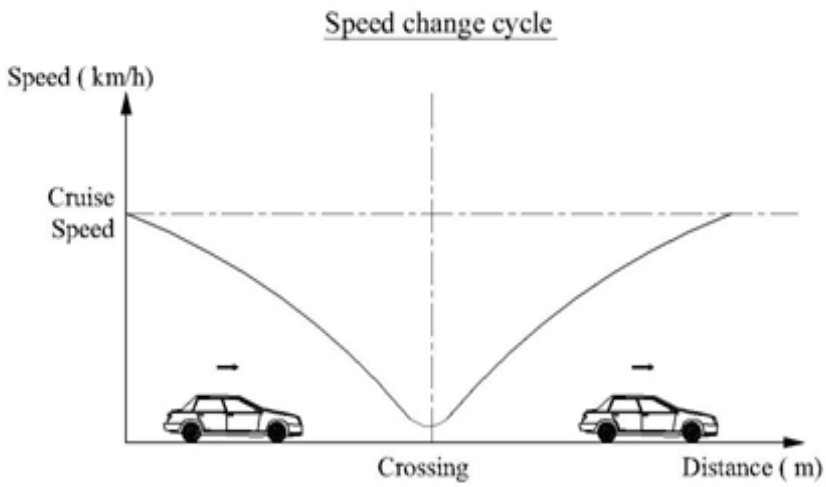

Figure 7. Speed change cycle

Table 2. VOC relative to cost of operating cars

Cost Category	Motorcycle	3- Wheeler
Fuel & Oil	42%	50%
Tyres *	30%	40%
Maintenance & repairs	22%	35%
Depreciation	40%	70%

*(*Based on difference in wear, in number of tyres, and in tyre costs)*

(Source: Assessing public investment in transport sector- Department of National planning – Ministry of finance & planning – Sri Lanka)

Additional VOC Values are provided by vehicle classes and the vehicle classes are defined as follows.

Table 3. Vehicle classes

1	*MCL*	*Motor cycles*
2	*TWL*	*Three wheelers*
3	*CAR*	*Passenger cars*
4	*LCV*	*Light Commercial Vehicles* (Vans, utilities and trucks up to 3.5 tonnes, gross laden weight. LCV mainly have single rear tyres but include some small trucks with dual rear tyres).
5	*MCV*	*Medium Commercial Vehicles* (Two axle heavy trucks without a trailer, over 3.5 tonnes gross laden weight).
6	*HCV 1*	*Heavy Commercial Vehicles 1* (Rigid trucks with or without a trailer, or articulated vehicle, with three or four axles in total).
7	*HCV 11*	*Heavy Commercial Vehicles 11* (Trucks and trailers and articulated vehicles with or without trailers with five more axles in total).
8	*LBU*	*Large Passenger Vehicles* (Buses, excluding minibuses).

Additional VOC for passenger car due to speed change cycle is given in Table 5. For an example, let us consider a passenger car which follows a speed change cycle from an initial cruise speed of 70 km/h to a minimum speed of 10 km/h before returning to the original cruise speed. Additional VOC is taken as 2.5 (in cents/speed cycle) for the intermediate values of speed change calculated from linear interpolating. Additional VOC due to speed change for each type of vehicles were calculated using vehicle operating cost tables except motorcycles and 3-wheelers which were not given in the NZ Transport Agency's Economic evaluation manual (volume 1).

Table 4. Passenger car additional VOC due to speed change cycles (cents/speed cycle)

Initial speed (km/h)	Additional VOC (in cents/speed cycle) by final speed																							
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
5	0.1																							
10	0.2	0.1																						
15	0.3	0.2	0.1																					
20	0.4	0.3	0.1	0.1																				
25	0.6	0.4	0.3	0.2	0.1																			
30	0.8	0.6	0.5	0.4	0.2	0.1																		
35	0.9	0.8	0.7	0.5	0.4	0.2	0.1																	
40	1.1	1.0	0.9	0.8	0.6	0.4	0.2	0.1																
45	1.4	1.2	1.1	1.0	0.8	0.6	0.4	0.2	0.1															
50	1.6	1.5	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.1														
55	1.8	1.7	1.6	1.5	1.3	1.0	0.8	0.6	0.4	0.2	0.1													
60	2.1	2.0	1.9	1.7	1.6	1.3	1.1	0.8	0.6	0.4	0.2	0.1												
65	2.4	2.3	2.2	2.0	1.8	1.6	1.3	1.1	0.9	0.6	0.4	0.2	0.1											
70	2.7	2.6	2.5	2.3	2.1	1.9	1.6	1.4	1.1	0.9	0.6	0.4	0.2	0.1										
75	3.0	2.9	2.8	2.6	2.4	2.2	1.9	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1									
80	3.3	3.2	3.1	2.9	2.7	2.5	2.2	2.0	1.7	1.4	1.2	0.9	0.7	0.4	0.2	0.1								
85	3.6	3.5	3.4	3.3	3.1	2.8	2.5	2.3	2.0	1.7	1.5	1.2	0.9	0.7	0.4	0.2	0.1							
90	4.0	3.9	3.7	3.6	3.4	3.1	2.8	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1						
95	4.3	4.2	4.1	3.9	3.7	3.4	3.1	2.9	2.6	2.3	2.0	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1					
100	4.7	4.5	4.4	4.2	4.0	3.7	3.4	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1				
105	5.0	4.9	4.7	4.6	4.3	4.0	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	1.0	0.7	0.4	0.2	0.1			
110	5.4	5.2	5.1	4.9	4.6	4.3	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.1	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1		
115	5.7	5.6	5.4	5.2	5.0	4.7	4.4	4.1	3.8	3.5	3.2	2.9	2.6	2.3	2.0	1.8	1.5	1.2	0.9	0.7	0.4	0.2	0.1	
120	6.1	5.9	5.7	5.5	5.3	4.9	4.6	4.3	4.0	3.7	3.4	3.1	2.8	2.6	2.3	2.0	1.7	1.4	1.2	0.9	0.6	0.4	0.2	0.1

(Source: NZ Transport Agency's Economic evaluation manual, Vol. 1)

Additional VOC for passenger cars could be determined for each time slot as indicated in Table 4. As example, the values for Kaduwela direction are indicated in Table 5.

Table 5. Additional VOC for passenger cars to Kaduwela direction

To Kaduwela					
Time	Initial speed (km/h)	Final speed (km/h)	CAR	Additional VOC due to speed change cycle (cents/speed cycle) for one vehicle	Additional VOC due to speed change cycle (cents)
06:00-08:00	46	13	352	1.09	383.7
08:00-09:00	48	12	233	1.22	284.3
9:00-12:00	51	26	400	0.80	320.0
12:00-14:00	49	13	254	1.23	312.4
14:00-16:00	51	26	265	0.80	212.0
16:00-18:00	48	14	352	1.15	404.8
18:00-22:00	54	31	726	0.59	428.3
22:00-06:00	61	60	764	0.02	15.3
Total					**2360.8**

Similarly, additional VOC towards Malabe direction could be also determined and tabulated as above. Then the additional VOC for all vehicle classes, LCV, MCV, HVC I, HCV II and LBU were determined and tabulated separately for both directions. Finally total additional VOC per day for both directions could be summed and tabulated as follows (Table 6).

Table 6. Total additional VOC for both directions

Additional VOC due to speed change (cents)			
Types of vehicles	To Malabe	To Kaduwela	Sub total
MCL	1546	920	2466
TWL	1266	752	2018
CAR	3920	2361	6281
LCV	4608	2853	7461
MCV	4452	2818	7270
LBU	5431	3431	8862
HCV I	11771	7522	19293
HCV II	1349	801	2150
Total			**55801**

The total Additional VOC due to Speed change
in the road section (per day) = 55801 (NZ cents)
= 558.01 (NZ dollars)
(1 NZ dollar = Rs. 106.2)
= 558.01 x 106.2
= **Rs. 59,260**

4. Additional travel time

The speed of traffic is interrupted due to the existing pedestrian crossing and it decelerates to a minimum speed (which may be a complete stop) before accelerating back to its original cruise speed. The additional travel time for a speed change cycle is the difference in travel time for traveling the distance of the speed cycle at the original cruise speed versus through the speed cycle. Table 7 indicates additional travel time (in seconds per speed cycle). Additional travel time for each vehicle class during each time slot was

also determined by using additional travel timetables and the procedure is similar to how the additional VOC was determined.

Table 7. Total additional travel time for all vehicles categories

Additional travel time due to speed change (seconds)				
Types of vehicles	To Malabe	To Kaduwela	Total additional travel time	
			(seconds)	(hours)
CAR	52894	31716	84610	23.50
LCV	22032	13219	35251	9.79
MCV	8124	4912	13036	3.62
LBU	4651	2799	7450	2.07
HCV I	8946	5401	14347	3.99
HCV II	517	291	807	0.22

5. Value of time (VOT)

Travel time is important for vehicle occupants, passenger transport users, pedestrians, cyclists, and freight vehicles etc. The road user values are used to produce travel time values for uncongested and congested traffic conditions. Values of time must be adjusted to reflect the appropriate value for the study year. Since VOT is income based, the most rational index would be based on changes in per capita income. Monthly income by income groups can be obtained from the most recent (*e.g.* 1996/97) Consumer Finance & Socioeconomic Surveys conducted by the Central Bank of Sri Lanka.

Table 8. Value of time for all vehicles categories (per one vehicle)

Types of vehicles	Passengers per vehicle	Value of time (VOT) per one passenger in 1999(Rs/hour)	Value of time (VOT) per one passenger in 2011(Rs/hour)	Value of time (VOT) per one vehicle in 2011(Rs/hour)
CAR	2	78.62	424.39	848.78
LCV	4	37.62	203.07	812.28
MCV	2	23.01	124.21	248.42
LBU	60	12.41	66.99	4019.40
HCV I	2	23.01	124.21	248.42
HCV II	2	23.01	124.21	248.42

Table 9. Total additional travel time

Types of vehicles	Total additional travel time (hours)	Cost for additional travel time due to speed change per hour	Total cost for additional travel time (Rs)
CAR	23.50	848.78	19,948.64
LCV	9.79	812.28	7,953.76
MCV	3.62	248.42	899.56
LBU	2.07	4,019.40	8,317.39
HCV I	3.99	248.42	990.03
HCV II	0.22	248.42	55.72
Total			**38,165.09**

Total additional VOC per a typical day for all vehicle classes were computed, as they underwent a speed change cycle due to the existing pedestrian crossing. That amount of Rs. 59,260 is the sum of all breakdown components of VOC which are fuel and oil, tyres, maintenance and repairs, depreciation. The percentage of total base VOC by component for each vehicle type also computed. Therefore total additional cost per day for each component of VOC can be calculated.

At the same time, for the same speed change cycle, additional travel time per day for all vehicle classes was determined. The total cost for additional travel time of all vehicles classes was calculated by considering the annual income of different road users. The total cost time for additional travel time of all vehicle classes per day is Rs. 38, 165.

Since the total cost for additional travel time, the total cost for fuel and oil wastage, total cost for tire wastages, total cost for maintenance and repairs, total cost for depreciation per day is known, by taking in to account of the traffic growth rates and future traffic in Colombo district the total cost saving can be computed.

6. Capacity design of overhead bridge

By considering road capacity for year 2032 (*i.e.* 20 years from present) it was proposed to improve the road to a reasonable road width consisting of sufficient number of lanes (6) for a desirable level of service. It was also found that a pedestrian crossing of 2 m width is required to cater to future pedestrian volume in year 2032 as per us highway capacity manual. Hence the overhead pedestrian crossing was designed.

Results and Discussion

Calculated total cost of the project and cost saving from the new structure is as follows:

Total construction cost of project (as per year of 2012)	= Rs.124, 000,000
Cost saving from additional VOC (per day)	= Rs. 59,260
Cost saving from additional travel time (per day)	= Rs. 38,165
Cost saving per year 1 (Rs. 59,260 + Rs. 38,165) x 365	= Rs. 35,560,125 → (Rs. 35,560,000)

Expected Internal Rate of Return of this project is 13.4% and it should be compared with minimum rate of return in order to make an investment decision. The proposed overhead pedestrian crossing will cost 124 million rupees in 2012 and it is expected to save 35.56 million rupees per year over the next 5 years. By considering the allowable minimum Treasury bill rates of capital which is 12% and since it is exceeding it, (IRR value 13.4%) the project seems to be viable.

Conclusions and Recommendations

It was shown that the best possible way to ensure reduced vehicle operating cost and safe travel along this road stretch for commuters was by constructing a new pedestrian's

overhead bridge. A complete separation of pedestrian and vehicle movements will be only possible through an overhead pedestrian crossing or an underground pedestrian crossing (pedestrian subway). Although an underground pedestrian crossing (pedestrian subway) is also an option, due to its excessive cost and disturbance to traffic during the construction phase (i.e. when constructing across a road having Average Daily Traffic (ADT) of 39,800) the underground crossing (pedestrian subway) was not considered.

The proposed width of 2 meters of the overhead crossing structure will serve the forecasted pedestrians volume at a reasonable LOS, even after twenty years from now. At present, the capacity of Malabe - Kaduwela road is not adequate, and improvement is needed to overcome the anticipated future traffic congestion along this road section by improving up to 4 lanes. With suggested improvements, initially the LOS of the road will improve considerably, but in twenty years time, it will reach the present level of service of the road if present traffic growth rates persist. As the IRR of this investment exceeds its cost of capital (10% - 12%), the project can be undertaken. This project is considered to be profitable and execution of the project is justified.

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Introducing Herbicide Resistant Crops to Sri Lanka: A Review

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Abstract

Over the last three decades substantial effort has been made to breed herbicide resistant crops (HRCs) and introduce them as a measure to relieve the constraints imposed by different combinations of chemicals, solving problems associated with herbicide residues, expansion of the range of compounds available, simplify crop management and extending the useful life of currently utilizing herbicides. A limited number of HRCs have been commercialized in the last three decades and a majority of these crops are cultivated in developed countries. Although evidences support that farmers can benefit from HRCs, there are many concerns about the health risks and environmental impacts related to HRCs. As an agriculturally based developing country, introduction of HRCs and their impacts could be an important issue to Sri Lanka. The farmer's main concern is to produce as much crop as possible with a high yield to meet the consumer demand. Therefore, the national level institutional capacity, scientific infra-structure and financial support need to be expanded for the development of country's own biotechnological programs to produce new crop cultivars. Further, focus is a need in comprehensive studies to fully assess the potential benefits and adverse consequences of introducing HRCs in Sri Lanka. Thus, the best alternatives would be to look for naturally accessible HRC germplasms, crop rotation, and sustainable farming practices including sustainable herbicide utilization to compete with weeds.

Keywords: Bio-pollution, Herbicide resistant crops, Sri Lanka, Weeds

Introduction

Limitation of land resources and ever growing human population demand a rapid increase in the crop production to fulfil the food demand and security to feed the population. The emergence of weeds in cropping system becomes a major challenge to the increasing crop productivity.

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Weeds are not only competing with crop plants affecting yield quantity and quality but also obstruct harvesting efficiency and contribute to the persistence and spread of pests and diseases. Since the Second World War chemical herbicides have largely replaced labour intensive cultural regimes in weed control (Duke, 1996). Herbicides fall into two categories. Selective herbicides have been specially developed for particular crops that have natural tolerance to them. Non-selective (also referred to as broad-spectrum) herbicides are effective against virtually all plants that can, therefore, only be used in special circumstances where they do not contact the crop (Duke, 1996).

The use of synthetic herbicides in agriculture flourished with the arrival of selective, auxinic herbicides (*e.g.* 2, 4-D) in the middle of the last century. Since then, herbicide manufacturers have attempted to develop herbicides that would kill more or all of the problematic weeds without damaging the crop. Over the last half of the 20th century, many classes of selective herbicides with a varing of modes of action were discovered and developed. During the development of herbicides, herbicide molecules were tailored to provide greater selectivity, efficiency and safety. Some exceptional non-selective herbicides such as paraquat, glufosinate and glyphosate were also developed.

Though the herbicide development culminated in the past, herbicide-resistant weeds have been discovered in early 1970s. This discovery triggered an interest on developing herbicide resistant crops using crop breeding techniques. Advancement of molecular genetics made it possible to incorporate herbicide resistant genes from unrelated organisms into a susceptible crop.

Over the last three decades, considerable effort has been made to breed herbicide resistant crops (HRCs) and it was expected to relieve the constraints imposed by different combinations of chemicals, overcome problems associated with herbicide residues, expand the range of compounds available for selective use in-crop, simplify crop management and extend the useful life of current non-selective herbicides (Senior & Bavage, 2003).

Proceeding to the advent of modern biotechnology, there was a limited effort to find or breed cultivars that were resistant to particular herbicides. Shortly after the first weeds evolved resistance to herbicides, scientists began to consider altering crops to make them resistant to herbicides. Initially, non-

transgenic methods were used. A breeding program was initiated to move resistance from *Brassica rapa* L., that evolved resistance to triazine herbicides to other *Brassica* spp. crops (Hall *et al.*, 1996). This approach was used to produce several triazine resistant canola varieties, which were released in 1980s. A number of HRCs were commercially grown since 1984 during which the first triazine-resistant oilseed rape cultivar (OAC Triton) was introduced to the Canadian market (Hall *et al.*, 1996). However, no other triazine resistant crops were developed. Since then other non-transgenic methods such as whole-cell selection, mutagenesis and plant selection from natural populations have been used to produce sulfonylurea-resistant soybeans, sethoxydim-resistant maize and several imidazolinone-resistant crops (Green & Owen, 2011).

In the early 1980s, the tools for producing transgenic crops became available. This technology was used to produce crops resistant to a very broad spectrum of herbicides such as glyphosate and glufosinate. Thus, HRCs were the first commercialized transgenic crops. Another early HR transgenic crop available to farmers was bromoxynil-resistant cotton in 1995 (Stalker *et al.*, 1996). A transgene encoding a plasmid-encoded nitrilase from *Klebseilla ozaenae* was used to generate plants that rapidly degrade bromoxynil to non-toxic benzoic acid derivatives of bromoxynil. Additionally, transgenic bromoxynil-resistant canola was introduced in 2000. None of these bromoxynil-resistant HRCs constitute a significant market share (Duke, 2005). However, they have been very useful when the weed pressure from bromoxynil-susceptible weeds was a problem. Since bromoxynil was not a broad-spectrum herbicide, introduction of these HRCs simply added another selective herbicide to those already available for use on these crops.

Introduction of transgenic crops that are resistant to a broad-spectrum of herbicides allowed the use of non-selective herbicides in weed management. The two mostly used non-selective herbicides in transgenic crops are glyphosate and glufosinate. Both of these herbicides have molecular targets in amino acid biosynthesis pathways. At present, most of the widely planted HRCs are glyphosate-resistant. Among these crops, glyphosate-resistant soybean and canola were introduced in 1996, cotton in 1997, and maize in 1999 (Duke, 2005). HRCs were first produced using the traditional breeding methods, whereas a large number of currently used HRCs have been produced by application of genetic

engineering. This technology has unintentionally positioned these crops in a hostile debate on the introduction and commercial use of genetically modified (GM) crops (Duke, 2005).

Although GM crops are being grown in an area of over 50 million ha., only a limited number of HRCs have been commercialized for the last two decades (Table 1) including rice, soybean, wheat, canola, cotton, sugar beet and sunflower (Green & Owen, 2011). A major contributing factor in this regard is the pressure exerted by certain groups on major food companies to reject products derived from GM crops, and the risk of reduced sales if they do not do so. In addition, misinformation concerning regulatory requirements and product safety testing has also had a negative effect on public confidence in the technology. Scientists have also employed a wide range of non-transgenic techniques to create crops with resistance to a number of herbicides (Table 1). For instance, the first commercial ACCase-resistant crop was a sethoxydim-resistant (SR) corn with an altered ACCase created using tissue culture selection (Somers, 1996). A second ACCase trait is in the final stages of commercialization for use in sorghum. This trait was transferred with traditional breeding methods from feral sorghum (shattercane, *Sorghum bicolor* L. Moench) that had evolved ACCase herbicide resistance because of agronomic practices. (Tuinstra, 2008).

As far as Sri Lanka is concerned, the literature on the HRCs in Sri Lanka is inadequate and limited work is reported for naturally occurring herbicide resistance in crops. However, glyphosate resistance in rice was reported for ten inbred-cultivated rice varieties (Bg250, Bg94-1, Bg304, Bg359, Bg406, Bg379-2, Bg366, Bg300, Bw364, and At362) and three traditional rice varieties ("Kalu Heenati", "Sudu Heenati", "Pachchaperumal" (Weerakoon *et al.*, 2013a). Therefore, the scarcity of literature on HRCs in Sri Lanka indicates that there is a need of prioritising studies related to HR. Initiation of such studies should emerge through the involvement of government organizations.

Table 1. Summary of Transgenic and Nontransgenic Herbicide-Resistant Crops (Green & Owen, 2011)

Crop	**Herbicide(s)**
Transgenic Herbicide Resistant Crops	
Cotton	Glyphosate, Glufosinate, Bromoxynil
Corn	Glyphosate, Glufosinate
Soybean	Glyphosate, Glufosinate
Non-Transgenic Herbicide Resistant Crops	
Canola	Triazine, Bromoxynil, Imidazolinones, Glyphosate, Glufosinate
Wheat	Terburryne, Imidazolinone
Soybean	Sulfonylurea, Atrazine, Glyphosate
Rice	Imidazolinone
Corn	Imidazolinone, Sethoxydim
Sugarbeet	Imidazolinone, Glyphosate
Alfalfa	Glyphosate
Sunflower	Imidazolinone

Developing Herbicide Resistant Crops

It is increasingly difficult to discover a new herbicide and even more difficult to find one with a novel mode of action. At present, approximately 500,000 compounds need to be screened to discover a potential herbicide compared with one per 500 compounds screened in the 1940s. Since then there are difficulties in discovering new herbicides, expanding the utility of existing herbicides that have a broad weed-control spectrum and good environmental profile. Biotechnology approach is a useful

strategy for advancing the development of selective herbicides (Tan *et al.*, 2005; Devine, 2005). There are basically four means of developing herbicide resistant plants.

Breeders have been involved in modifying the genetic make-up of plants through conventional breeding methods for a long period. They have developed new crop varieties using the existing genetic variability or by creating new variability, which is the prerequisite for any breeding programme. Conventional breeding of herbicide resistant plants were developed as a result of sexual hybridization, backcrossing and pedigree breeding techniques. The first licensed atrazine tolerant canola (*Brassica napus* L.) cultivar "OAC Triton" became available in 1981. This was developed by conventional breeding techniques as a result of sexual hybridization and backcrossing with *B. rapa* L. (Bird's rape) that had evolved tolerance to the herbicides (Senior & Bavage, 2003).

Plant genetic transformation is the science of direct gene transfer and integration, from one plant to another or from a microorganism to a plant, to create plants with altered genetic make-ups to achieve specific crop production goals. The altered plants are generally termed transgenic (or genetically modified-GM). A number of GM crops expressing various traits have been commercialized and several others are at various stages of development (Tsaftaris, 1996). Until today, HR transgenic crops have been the most widely used type of transgenic crops. In 2008, worldwide, 63% of all agricultural land devoted to transgenic crops involved HR transgenic ones, and the percentage was higher (85%) when the herbicide-tolerant trait was stacked with another (Bonny, 2009). Transgenesis for herbicide resistance involves the identification of an herbicide resistant gene from a plant or microorganism, its isolation and manipulation for efficient plant expression (if it is of microbial origin) and its subsequent delivery, stable integration and expression in the cells of the target crop plant. For the most part, a gene coding for useful HR in crops is isolated from herbicide degrading soil microorganisms (James, 2003).

A number of techniques are now available for the transfer of genes (genetic engineering) into crop plants, including *Agrobacterium*-mediated gene transfer, micro-projectile (or particle) bombardment, polyethylene glycol-mediated DNA transfer and cell (protoplast) electroporation. The most commonly employed techniques in developing HRCs are the *Agrobacterium* and the

particle bombardment methods. Herbicide resistance *via* genetic transformation can be conferred by one of the following methods (Mulwa & Mwanza, 2006):

1. Introduction of a gene(s) coding for a herbicide detoxifying enzyme(s); and
2. Introduction of gene(s) coding for a herbicide insensitive form of a normal functioning enzyme or over expression of the genes coding for a herbicide target enzyme such that the normal metabolic functioning is still achieved in the plant even though some of the enzyme is inhibited.

At present, only five transgenes have been used in commercial crops to confer resistance to herbicides. *Agrobacterium* sp. strain CP4 which encodes5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS), GOX (glyphosate oxidorreductase), GAT (glyphosate acetyl-transferase) and the mutated maize EPSPS genes which have been used for glyphosate resistance, the gene encoding a nitrilase for bromoxynil resistance, and the *bar* gene for glufosinate resistance. Several glyphosate-resistant crops such as soybean, cotton, canola *etc.* were developed by introgresssing the CP4 gene from *Agrobacterium* sp., which encodes a resistant form of EPSPS (Padgette *et al.*, 1996). The glyphosate-resistant canola also contains a gene that encodes GOX from the microbe *Ochrobacterium anthropi* (strain LBAA). Glyphosate oxidorreductase degrades glyphosate to glyoxylate and aminomethylphosphonate (AMPA), a non-toxic compound. The *bar* gene from *Streptomyces hygroscopicus* makes plants resistant to glufosinate by inactivating this herbicide through acylation (Reddy *et al.*, 2004). Many crop species such as corn,cotton, canola, have been successfully transformed with this gene.

Chemical or physical mutagenesis of seed, microspores or pollen followed by selection under herbicide selective pressure has also been utilized to develop resistance to herbicides in crops. Mutagenic agents such as nitroso ethyl urea (NEU), nitroso methyl urea (NMU) and ethyl methane sulphonate (EMS) are potential inducers of mutations in chloroplast DNA (Venkataiah *et al.*, 2005). The most common method of mutagenesis includes the use of EMS (McCabe *et al.*, 1990). In this method, seeds or pollen are treated with EMS then grown either *in vitro* or *in vivo* in the presence of a herbicide. Surviving plants are selected and grown to maturity to provide seed that is used for further screening with herbicides. Utilizing this method, Sandhu *et al.* (2002) developed

21 Brazilian rice lines that were resistant to glyphosate. Ashfaq-Farooqui *et al.* (1997) produced atrazine resistant *Solanum melongena* plants by mutagenizing seeds followed by germination and *in vitro* regeneration of plants from the resultant seedling cotyledons.

Ultra-violet (UV) or EMS treated microspores or pollen can be grown *in vitro* into haploid plantlets whose chromosome number can be doubled to create instant inbred lines bearing a specific herbicide tolerant trait. Ahmad *et al.* (1991) used microspore UV mutagenesis and haploid culture to develop canola plants that were resistant to chlorsulfuron. Imidazolinone tolerance in oilseed rape has been obtained by microspore mutagenesis (Mulwa & Mwanza, 2006). This approach relied upon somoclonal variation in the culturing of pollen, which gave rise to mutant haploid plants that could be chemically induced to double their chromosomes to form homozygous mutant cultivars.

Imidazolinone-resistant rice was developed through chemically induced seed mutagenesis with EMS (Gealy *et al.*, 2003; Tan *et al.*, 2005). Further, IMI rice ("Clearfield") was engineered through mutation by radioactive bombardment to tolerate imidazolinone herbicides and IMI rice has been adopted for its use in USA, Costa Rica, Colombia and Uruguay (Annou *et al.*, 2001). In Sri Lanka, attempts were made to induce and enhance naturally existing glyphosate resistance in traditionally cultivated and inbred cultivated rice varieties using induced seed mutagenesis with NaN_3 (Sodiun azide) and EMS (Weerakoon *et al*, 2013b). According to the findings NaN_3-treatment enhanced naturally existing HR in four inbred and one traditional rice varieties and induced HR in two susceptible rice varieties. EMS-treatment induced HR in five inbred rice varieties and two traditional rice varieties. Further, EMS enhanced naturally existing HR in three inbred and one traditional rice variety. Similarly, metribuzin tolerance in narrow-leafed lupin (*Lupinus angustifolius*) has been obtained by treating seeds with NaN_3 (Si *et al.*, 2009). However, none of the HR lupin varieties have been commercialized so far.

Plant tissue culture represents the simplest of the biotechnologies available to plant scientists today. The plants, which are produced by culturing tissues, are tested for their sensitivity to a particular herbicide. This procedure is repeated preferably with increasing amounts of said herbicide to provide a herbicide-tolerant/resistant strain of plant tissue which is subsequently

subjected to differentiating growth conditions to provide herbicide-tolerant plants. These plants can be propagated vegetatively using tissue culture methods to produce additional plants of the same genetic constitution. The plants also can be sexually reproduced to provide seeds and plants, which display inherited tolerance to the said herbicide (Mulwa & Mwanza, 2006).

Cell culture under lethal concentrations of certain herbicides also results in gene amplification in surviving cells that leads to resistance through the overproduction of enzymes targeted by herbicides. A carrot cell line with resistance to glyphosate was selected in this manner and subsequently plants were regenerated that were resistant to the sulfonylurea herbicide, chlorsulfuron (Caretto *et al.*, 1994). *In vitro* development of phosphinothricin (PPT) resistant rice has also been reported by inducing plantlet regeneration in explants collected from 7-day old seedlings on medium supplemented with sublethal doses of PPT (Toldi *et al.*, 2000). Other *in vitro* cell selection studies have resulted in the development of resistance to paraquat in tomato cells (Thomas & Pratt, 1982), resistance to glyphosate in carrot and groundnut cells (Murata *et al.*, 1998; Jain *et al.*, 1999) and resistance to a Protoporphyrinogen oxidase (PPO) inhibitor in soybean cells (Warabi *et al.*, 2001).

The Benefits of Herbicide Resistant Crops

There are growing evidences that HRCs provide significant benefit to farmers (Devine & Buth, 2001). Farmers benefit from the excellent broad-spectrum weed control provided by such herbicides and from substantially lower costs of growing some HRCs. These factors have encouraged the adoption of HR corn, soybean and cotton in the USA and HR canola in Canada (James, 2003). HRCs provide additional crop choice, enabling implementation of alternate weed management tactics to target specific weeds while maintaining crop sequences. Therefore, it is believed that inclusion of an HR crop in a cropping program along with a range of weed management tactics can ensure to control hard-to-control weeds (Beckie *et al.*, 2006). Triazine tolerant canola has been used as an effective break crop in paddocks infested with wild radish, whereas conventional canola, faba beans, chickpeas and lentil are not viable choices in these paddocks, thereby limiting the number of available break crops (Devine & Buth, 2001).

Although there is a great concern among the general public, studies suggest that the use rate (unit weight per unit area) of herbicides in HRCs is not substantially different from that in conventional crops (Duke, 2005). The two main herbicides used in HRCs, glyphosate (Roundup) and glufosinate (Basta) have relatively short soil half-lives, and neither moves easily to ground or surface water (Duke *et al.*, 2003). Although there is concern about the possible effects of HRCs on soil health, there is no evidence that currently released HR crops cause significant direct effects on stimulating or suppressing soil nutrient transformation in field environments (Motavalli *et al.*, 2004).

As far as GM organisms are concerned, most regulatory systems only consider indirectly on the issue of whether or not the GM products are useful. According to European regulation (2001/18/EC) it is totally assumed that if a product is commercially viable it is useful. However, an alternative definition to usefulness could be that the product must fulfil important community needs (Madsen *et al.* 2002a). HRCs have mainly been developed to benefit farm-management, whereas benefits to consumers are less apparent. The general advantages appear to be linked with the fact that HRCs enable farmers to employ a flexible and easy management strategy. For some HRCs, it is possible to replace herbicides with a less favourable environmental profile. Some crops (cotton and canola) have led to significantly decrease (13%) the usage of herbicide, measured as active ingredient applied per hectare. It has been reported that HRCs allowed lowering the herbicide usage by 14% reduction worldwide (Brooks & Barfoot, 2007).

Glyphosate-resistant soybean has been adopted mainly because it simplifies weed control to the use of a single herbicide and with a more flexible timing than that required for conventional herbicides. Because, glyphosate is strongly adsorbed to the soil thus, there is a negligible threat of residual effects on subsequent rotational crops. The number of herbicide applications in soybeans is estimated to have dropped by 12%, between 1995 and 1999. However, when this is measured in terms of the total amount of active ingredients used, there seems to be an increase. Increasing herbicide use in soybean in the United States could partly be explained by the increased area sown with this crop (Carpenter & Giannessi, 2001). The American Soybean Association states that glyphosate-resistant soybean protects the environment

through changes in tillage practices and herbicide application, and also by improved weed control (Anderson, 2001).

Similarly, HR-rice varieties (IMI rice or "Clearfield") are now commercially available (Annou *et al.*, 2001). From an agronomic viewpoint, two main reasons are frequently put forward to justify the development and introduction of HR-rice. The first reason is to improve control of the weed flora (especially red rice and other weedy rice species) associated with this crop, (Olofsdotter *et al.* 2000; Gealy and Dilday, 1997). The second reason is to provide an alternative tool for the management of weeds that have already evolved resistance to particular herbicides, especially grasses such as *Echinochloa* spp. (Olofsdotter *et al.* 2000; Wilcut *et al.* 1996). HR-rice, furthermore, allows for the substitution of some of the currently used herbicides by others less detrimental to the environment (Olofsdotter *et al.* 2000). In many areas in the world, soil erosion due to tillage practices is a problem. In general, HRCs may be favourable to the environment by allowing for flexible weed management compared to conventional systems. This may allow farmers to practice conservation tillage, *e.g.* no-till or reduced tillage, and thereby reduce soil erosion (Duke, 2005). A wide collection of other combinations of current and new herbicide resistance traits is expected within the next decade. If used correctly, these multiple HRCs will provide new uses for existing herbicides to help growers better manage weeds. By using diverse weed management practices, growers will preserve the utility of herbicide resistance traits and herbicide technologies and help maintain profitable and environmentally sustainable crop production systems for future generations (Green & Owen, 2011).

The dose-response curves also could be used to evaluate the effectiveness of HRCs. The dose-response relationship for a particular combination of herbicide and plant species under specific growth stage and climatic conditions could be described as in Figure 1. Figure 1.A illustrates a non-selective herbicide and the desired control level for the weed and Figure 1.B shows what happens when the crop in Figure 1.A is made tolerant to an otherwise non-selective herbicide

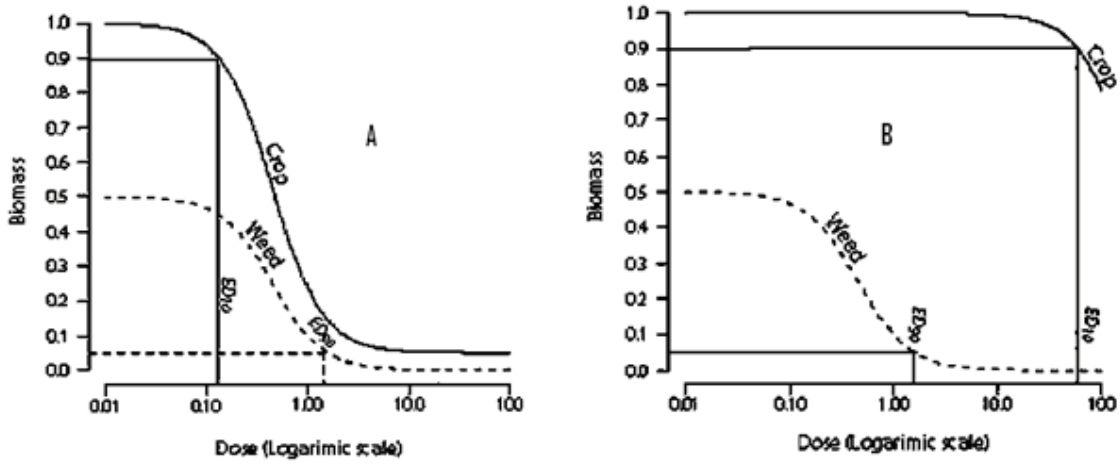

Figure 1. Dose response curves (Madsen *et al.*, 2000)
A. Non-selective herbicide, both weed and crops are susceptible
B. The crop in A has been made tolerant to the herbicide giving a very high index of selectivity

The Risks and Environmental Impacts

The risks of HRCs can be estimated qualitatively on the possibility and severity of immediate and delayed adverse effects to human health, environment and farmer's economy. The possibility and severity of each unwanted effect associated with HRCs depends on the crop, the HR trait, the local weed flora, climatic conditions and farm management practices and is possible to estimate on a case-by-case basis (Madsen *et al.* 2002b).

The optimal weed control in glyphosate-resistant crops, often requires sequential applications with glyphosate, and the timing relative to weed emergence (Swanton *et al.* 2000). When glyphosate is sprayed 2-3 times annually at high rates, it imposes a high selection pressure on weeds. In 5-8 years this could cause shifts in weed composition towards species that naturally tolerate glyphosate (Benbrook, 2001; Shaner, 2000). Then other herbicides may be needed to control these herbicide tolerant weeds (Shaner, 2000).

Increased herbicide use is considered as a risk worldwide. There are suspicions that herbicide use will increase as a result of HRCs. Two major explanations could be given why herbicide use in HRCs may increase. One reason is that a high level of crop tolerance can enable the farmer to increase doses to achieve an improved weed control without harming the crop. The other reason is the establishment of tolerant/resistant weeds and volunteers, which require farmers to increase dose or mix herbicides with different modes of action to maintain an acceptable level of weed control.

In addition, biodiversity within the field could be influenced if the herbicide, to which the HRC, is resistant. Furthermore, weed species respond differently to different herbicides or other weed-control measures and a shift in prevailing species is very likely. If an HRC is growing in a centre of genetic origin, then changes in the diversity of the indigenous species and risks of diminishing the genetic diversity of these species is a hazard (FAO, 2001). It is, however, very unlikely that HRCs will cause erosion of genetic diversity of wild species outside the cultivated land. Because the trait is associated with the use of herbicides which are not being applied in the wild, and a HR trait does not confer selective advantage unless the herbicide is used (Madsen *et al.* 1998). Therefore, there is a low risk of erosion of the genetic diversity of wild species growing in natural environments.

Further, gene flow, the transfer of genes from one population to another may lead to unwanted effects for weed management and the environment. It may enable resistance genes to move between HR and non-HR varieties and hence pollute a crop which is considered GM-free. HR-genes may be stacked from years of cross-pollination of HRCs, which may create problems to the farmer in controlling volunteer crops in the field. Multiple herbicide-resistant volunteer oilseed rape has been observed in Canada where oilseed rape with resistance to different herbicides was grown on neighbouring fields (Hall *et al.* 2000). Identification of successful hybridization between canola (*Brassica napus*) and wild mustard (*Sinapsis arvensis*) and between canola and wild radish (*Raphanus raphanistrum*) (Rieger *et al.*, 2001) caused some alarm amongst environmentalists. Potential gene flow from HR rice (*Orya sativa* L.) to different weedy rice (*O. Sativa* f. *spontanea*) was also reported recently (Song *et al.*, 2009). In addition, there has been a range of studies over the past 10- 15 years on gene flow between related species *i.e.* crop cultivars and their wild relatives (Table 2).

Table 2. Out-crossing and gene flow within and between different crop plants and relatives. Out-crossing frequency (OCF) is between closely situated plants. Isolation distance (ID) used in plant breeding. Gene flow is measured as potential (P) or actual (A) gene flow. (Source: Madsen & Jensen 1998)

Pollen Donor	Pollen receiving Species	OCF	Vector	ID (m)	Exp. det. Distance (m)	Frequency at max distance	Gene flow
Beta vulgaris	*B. maritima*	high	wind		75	0.06-0.31 %	A
Brassica napus	*Brassica napus*	22-36 %	bees (wind)	200	200	0.008 – 0.017 %	P
Brassica napus	*B. rapa*	13 %	bees	500			A
Brassica napus	*B. juncea*	some	bees	800			
Brassica napus	*B. oleracea*	some	bees	800			
Solanum tuberosum	*S. tuberosum*	low	bees		4.5	0.05 %	A
Pisum sativum	*P. sativum*	minimal	insects	1			
Hordeum vulgare	*H. vulgare*	0.5-5 %	wind				
Triticum aestivum	*T. aestivum*	<3 %	wind				
Secale cereale	*S. cereale*	55-100 %	wind		700	10 %	P
Cucurbita pepo	*C. texana*	high	bees	400	1300	0	A
Oryza sativa	*O. sativa* (red rice)	1-52 %					
Sorghum bicolor	*S. halepense* (Johnsongrass)	10-15 %	wind	200-400 m	hand-crosses	11 %	A
Helianthus annuus	*H. annuus*	27 %	insects	88	1000	2 %	A
Zea maiys	*Z. mexicana*	95 %	wind	180-750			A
Lupinus albus	*L. angustifolius*	8.4 %	bees	200	37.5	0.04 %	A

Many studies focused on hybridization within and between crops and wild relatives. According to data given in Table 2, there are many examples showing high out-crossing percentages between closely related cultivated crop species as well as between cultivated crop species and their wild relatives.

In case of the herbicide resistant genes, which are transferred to their wild relatives, these relatives could then develop herbicide resistance to become "super-weeds". Subsequently, the use of herbicide becomes redundant. In this situation, farmers need to use more herbicide, or to change the herbicide to one in which there is no resistance. However, the past has repeatedly shown that cropping system diversity is the pillar of sustainable agriculture. If the large-scale cultivation of HR crops adheres to this fundamental principle, it is possible to avoid the intense selection pressure for weed resistance and consequently, greater herbicide use in future to control HR weed biotypes (Beckie *et al*., 2006).

Alternatives to Herbicide Resistant Crops

It is worthwhile to find possible alternative technologies, either existing or in development, which are capable in replacing HRCs. Applications of herbicides and tillage practices have been the oldest way of controlling weeds. Although new herbicides are being developed, unlike broad-spectrum herbicides, glyphosate and glufosinate, the new herbicides, are unlikely to influence the use of HRCs significantly.

Conventional approaches to bio-control of weeds had little impact on weed management (Duke *et al.*, 2003). Research is underway to improve bio-control agents with transgenes (Duke, 2003; Duke *et al.*, 2003). However, this technology has considerably more environmental risk than HRCs. Research is also underway to make crops more allelopathic with transgene technology, expecting that herbicide use would be substantially reduced with such varieties (Duke *et al.*, 2002; Duke, 2003). There is concern that introgression of transgenes for this type of trait into wild species could increase fitness in their natural ecosystems, with unpredictable consequences.

Another alternative is to promote crop cultivars/varieties which are being cultivated processing herbicide tolerance or herbicide

resistance. A study conducted by Weerakoon *et al.*, (2013a) revealed that there were ten inbred cultivated rice varieties and three traditionally cultivated rice varieties in Sri Lanka processing natural resistance to glyphosate.

Suitability of Herbicide Resistant Crops for Sri Lanka

Sri Lanka is a country with an agriculture based economy, and the introduction of HRCs and their impacts is an important issue. The farmer's main concern is to produce as much crop as possible at the lowest cost to sell at the highest price. For many, this is an uphill task, and many find it hard to grow enough crops to live on. In recent years, Sri Lankan food imports have gone up, with even basic crops like rice, potato and green gram have to be imported to meet consumer demands.

In most of the developed world, the major crop species have been introduced from elsewhere, but many developing countries like Sri Lanka, India etc. are the centres of origin and centres of diversity of crops grown in these countries. Therefore, the risk of introducing alien genes into wild relatives could be somewhat higher in such countries (Kumar *et al.*, 2008). In these circumstances bio-pollution is possible which can destroy the original genetic diversity. Sri Lanka has a varied climate and topography, which has given rise to rich species diversity, believed to be the highest in Asia, in terms of unit land area. This is especially relevant for mammals, reptiles, amphibians and flowering plants. The biological wealth is distributed within a multitude of systems that have been broadly categorized as coastal and marine, forest, wetland and cultivated areas. Sri Lanka is also identified as one of the global biodiversity hotspots indicating its significance in biological wealth and threats to the biological wealth (National Bio-safety Framework of Sri Lanka, 2005).

Sri Lanka signed the Cartagena Protocol on Bio-safety on 24 May 2000, during the fifth meeting of the Conference of Parties to the Convention on Biological Diversity in Nairobi, Kenya. The country ratified Cartagena Protocol on 28 April 2004 and consequently the Protocol has entered into force in the country on July 2004. As a result the national bio-safety framework was established. The overall objective of Sri Lanka's national bio-safety framework is to ensure that the risks likely to be caused by modern biotechnology

and its products will be minimized and biodiversity, human health and environment will be protected in a maximum way regulating the trans boundary movements through formulation of relevant policies, regulations, technical guidelines and establishment of management bodies and supervisory mechanisms. Thus, bio safety framework is based on a precautionary approach. As a consequence, there are strict regulations and management of GMOs including GM crops imported to Sri Lanka and produced within the country (National Bio-safety Framework of Sri Lanka, 2005). Recently, bio-safety act of Sri Lanka has been discussed in many fora to be finalized as a parliament act. It has much concerns and restrictions on introducing transgenic plants/animals and transgenic products to Sri Lanka.

The evidences reviewed by Raney (2006) suggest that farmers in developing countries can benefit from GM crops. A considerably high level of institutional capacity at the national level is necessary to ensure that farmers have access to suitable newly developed seeds or other plant material on competitive terms. Up to a certain amount of national level research and regulatory capacity, effective IPR management and input supply systems are essential. The financial outcomes so far propose that farmers in developing countries can benefit from transgenic crops. However, for the underprivileged farmers in developing countries, where institutional conditions are poor, the benefits they gain from transgenic crops still remain questionable. Sri Lanka is a developing country with a limited national institutional capacity which lacks the necessary financial resources and is limited in the scientific infrastructure needed to develop their own biotechnology programs for the crops that are important to feed our people.

Further, the additional expenses of GM seeds compared to conventional/traditional varieties are significantly high. Therefore, at present, we are not in a position to rely on GM crops, including transgenic and non-transgenic HRCs to meet the national food demand. In addition to the poor economy in the country, environment and food safety regulations, social, health and environmental issues also contribute for GM crop restrictions.

About 90% of rice production and consumption worldwide occurs in Asia. In Sri Lanka, rice is the main food crop growing on 0.77 million ha in all agro climatic zones (Department of Agriculture, 2003). There are major concerns in attempting to introduce HR-rice to Asian countries, although HR-rice has the potential to

improve the efficiency of weed management (Kumar *et al.*, 2008). So far three HR systems have been developed in rice: imidazolinone-, glufosinate-, and glyphosate-resistant varieties (Gealy *et al.*, 2003). However, a recent survey in India exposed the many risks of introducing HR rice to South East Asian countries. The greatest risk in the commercialization of HR-rice is the potential for transfer of the gene conferring the HR trait to relative wild relatives. This could lead to increased weediness or invasiveness. Gene transfer between cultivated and wild or weedy rice is known to occur (Song *et al.*, 2009). In addition to gene flow from HR-rice to its wild and weedy relatives, gene flow from HR rice to conventional rice cultivars is another risk. The likelihood of such gene transfer is high in Sri Lanka and India, where cultivated rice and its relatives are symmetrically distributed and their flowering times overlap. Such gene flow can impact crop invasiveness, fitness of wild species, and the loss of native biodiversity. Additionally, HR rice may contribute to the problems of crop volunteers and evolution of herbicide resistance (Kumar *et al.*, 2008).

At present, there are only two HR weeds reported in Sri Lanka. It was reported that the weed Barnyardgrass (*Echinochloa crus-galli*) a monocot of the family Poaceae, first evolved resistance to Group C2/7 herbicides in 1997 and infests rice (Ntanos *et al.*, 2000). Group C2/7 herbicides are known as Ureas and amides (Inhibition of photosynthesis at photosystem II). Research has shown this species resistant to propanil and they may be cross-resistant to other Group C2/7 herbicides. The second weed Sumatran Fleabane (*Conyza sumatrensis*) is a dicot weed in the family Asteraceae and first evolved resistance to Group D/22 herbicides in 1998 and infests tea. Group D/22 herbicides are known as Bipyridiliums (Photosystem-I-electron diversion). Research has shown that these particular species is resistant to paraquat and they may be cross-resistant to other Group D/22 herbicides (Heap, 2007). The latest addition to HR weeds is weedy rice (*Oryza sativa f spontanea*), which was first reported in Sri Lanka in 1997 from the Ampara district (Marambe, 2009; Abeysekera *et al.*, 2010). This has become a major threat to Sri Lanka's paddy cultivation showing resistance to glyphosate (Abeysekera *et al.*, 2010). Thus, existing scientific literature related to benefits and risk of HRCs is limited and further detailed studies are needed to fully assess the potential beneficial and adverse consequences of widespread adaptation of HRCs in Sri Lanka.

Sustainable agriculture has given higher productivity and yields in developing countries (Pretty & Hine, 2000). According to IFOAM (2003), land area under organic management in Asia was the largest in China (301,295 ha) followed by Indonesia (40,000 ha), Sri Lanka (15,215 ha), Japan (5,083 ha), Thailand (3,429 ha), Pakistan (2,009), Taiwan (1,092 ha), Republic of Korea (902 ha), and Malaysia (131 ha). Sustainable agricultural practices tend to reduce soil erosion, as well as improve soil physical structure and water-holding capacity. Soil fertility is also maintained by various sustainable agriculture practices. Further, sustainable agriculture promotes agricultural biodiversity, which is crucial for food security and rural livelihood. Organic farming can also support much greater biodiversity (Institute of Science in Society, 2004). A similar sustainable strategy could also be adopted to utilize HRCs in Sri Lanka in future, *i.e.* cultivation of HRCs and non-HRCs in rotation along with proper herbicide combinations to minimize the gene-transfer from HRCs to their wild relatives to prevent evolving volunteer weeds.

Conclusions

The review of the literature on the HRCs led to the following conclusions.

- HRCs have a great potential in the simplification of weed management. If proper care is exercised in introducing HRCs, they may be beneficial to the environment by enabling no-till systems, thus reducing erosion or allowing for later weed control, which may increase bio-diversity in the field. However, it must be emphasized that the risk from HRCs should be carefully evaluated prior to releasing the HRC into a cropping system, especially when the HRCs possess weedy characters or may outcross with related weeds. If this is the case, and the HRC is grown commercially, then precautions need to be taken, similar to the management strategies adopted to prevent the development of naturally-resistant weeds. Furthermore, precautions must, in particular, be taken before release into the areas of genetic origin of a particular species.

- There is a need of extensive study on the potential issues related to the introduction of HRCs to Sri Lanka. A considerable portion of the National Budget of Sri Lanka is

devoted to the import of food to meet increasing consumer demands. Introduction of transgenic and other genetically modified crops and their impacts have become an important issue. The low-cost crop productivity and selling at the highest price would become another major concern. Therefore, there are many doubts about the benefit of such crops to farmers which are needed to be rectified.

- The country's higher biological diversity may have a higher risk of introducing alien genes through HRCs. This can lead to "bio-pollution" in Sri Lanka depleting native original genetic diversity and increase the number of HR weeds.

  Sri Lanka has a limited national level institutional capacity and most of such institutions have limited financial resources and the scientific infrastructure which is required to produce the new crop cultivars using our own biotechnology programs. The capacity should be built to address the issues to assess the potential beneficial and adverse consequences of introduction of HRCs to Sri Lanka.

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Looking Back Looking Forward: The Invention and Reinvention of Distance Education

The Open University of Sri Lanka (OUSL) has very generously conferred upon me, an honorary degree of Doctor of Letters for my "valuable contributions to the field of distance education regionally and internationally". This is a tremendous honour for which I am very grateful.

It is therefore imperative that I take this opportunity to reflect on the field of distance education, its journey during my lifetime and where it might go in the future.

Like many of you in this audience, I started off my career as a teacher. In fact, I recall making a very conscious decision about becoming a teacher because I liked the idea of going to school, and being around people who were going somewhere. Since then, I have remained passionate about teaching as a profession, so much so that a brief stint as a journalist early on in my career trajectory swiftly brought me back to teaching to where I felt I belonged.

My encounter with *distance education* occurred quite early in my professional life as well, when in the early 1980s I took up an appointment as an educational designer in the distance education centre at the University of the South Pacific. It is here where I saw the opportunities and the challenges of learning and teaching at a distance, a subject which formed the focus of my graduate studies and the many roles and positions I have served in throughout the world since then. That means more than 30 years of studying and working in the field in one form or another.

One of these roles has included editing the journal *Distance Education*, one of the oldest journals in the field. Volume 1, Issue number 1 of this journal carries an article by Desmond Keegan which identified six key attributes of distance education (see Keegan, 1980, p.33).

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These six attributes described what distance education looked like then! But what does it look like now? How are those defining attributes of distance education being interpreted today? Furthermore, what is it likely to look like in the foreseeable future? Let's take a look at them closely.

1. Separation of teacher and learner

Distance education methods grew out of the need to meet the educational needs of those who could not be in the same place and time with the teacher. Its aim was to release educational practice from the shackles of the four walls of the classroom and make it accessible to anyone who wanted and/or needed it, and not just those who could afford the time and money.

As such distance education was a liberating force as it embraced the notions of openness (see Lewis, 1986; Rowntree, 1992). Moreover, it was borne out of the need to serve a socio-economic and political agenda geared towards improving the quality of life of the not so privileged members of our society earning it the label "Learning at the Back Door" (see Wedemeyer, 1981).

Today of course, the concept of openness conjures a lot more than merely access to educational opportunity. It includes the need to adopt *open educational practices*, *open scholarship*, and the use of *open educational resources* in learning and teaching (see http://www.oer-quality.org/; Naidu, 2013a). The value proposition of the adoption of open educational practices generally, and open scholarship in particular, is that education is a basic need that should be accessible to all, and as Amartya Sen reminds us, the path to real freedom because it is education that opens doors to meaningful choices that are so essential for social and economic development (Sen, 1999). In order to achieve this goal, there is a need to redefine copyright while protecting the rights and intellectual capital of the creators of educational content such as that proposed by the Creative Commons license framework (see http://creativecommons.org/about).

No organization demonstrates this fundamental concept better than institutions such as the Open University of Sri Lanka, for had it not been for the educational opportunities that organizations such as the OUSL affords, many of us would not be here in this room today doing what we are doing!

2. Influence of an educational organization

A critical attribute that has most clearly separated distance education from all the other forms of formal and informal learning is its *organized nature*, such that it is not mistaken for *independent study or learning* in informal settings (see Wedemeyer, 1981; Latchem, 2014).

Traditionally these forms of organized learning and teaching activities have been called by various names such as *Distance Education*, *Distance Learning*, *External Studies, Extramural Studies, Off-Campus Studies, Independent Studies, Correspondence Education, and Continuing Studies, etc*. The term used to refer to this kind of organized educational activity had much to do with the educational tradition of the organization that was offering the programs. And the term "distance education", perhaps more widely used than others, has often been questioned as an adequate description of the various organizational models that have been emerging under that banner (Rumble, 1989).

So as in the early-1980s, just as the term distance education superseded the term correspondence education, a variety of terms have emerged to include various forms of learning and teaching that look like distance education, namely *Open Learning, Flexible Learning, Blended Learning, Distributed Learning, Online Learning, and eLearning*. Each of these terms is describing some aspect of distance education, for among all other things, their one common trait is *organized educational provision* that does not require the learners and teachers to be in the same place and time (Paine, 1989).

Today however, while the influence of the organization remains a hallmark feature of distance education, the range of providers is much broader and larger. These comprise dedicated distance teaching organizations, conventional campus-based organizations including reputable research-intensive Ivy League institutions such as Harvard, MIT and Stanford, virtual universities, and commercial, government and public sector agencies, as well as a whole range of private providers. There has been a tremendous expansion in organizations offering distance education programs so much so that it seems like everyone is offering such programs (see Gallagher & Garrett, 2013).

The nature of the "educational organization" is also undergoing change from its traditional bricks and mortar form located in a specific physical setting. The educational organization of the future might be an entity such as the OER University which leverages the affordances of the Internet and the Web to bring together learners, teachers and willing educational partners to make education available to anyone, anywhere and anytime (see http://www.oer-quality.org/tag/oer-university/).

Educational provision can no longer be seen as the sole right or responsibility of the privileged nor any particular type of organization. A variety of players are emerging on the scene to offer educational opportunities where it is needed, and in ways that best meet the needs of the students.

3. Use of media to unite teacher and learner

Something was required to bridge the physical separation of the distance learner from the teacher and the teaching organization without anyone moving physically. In the early days, this was the role of the printed study materials. And while the printed materials afforded a great deal of *flexibility* and *independence* to the distance learner, as a medium for uniting the teacher and learner and carrying the educational content, it had its limitations. Students as well as teachers hungered for more to improve their distance learning and teaching experience. Something had to be done to lift this somewhat impoverished picture of distance education as learning at the back door.

The availability of affordable technologies offered considerable hope. First there was multimedia, then audio and video conferencing and more recently online learning tools. The use of these technologies to "unite the teacher and learner and carry the educational content", as Keegan had put it, has made the distance learning experience a lot more *effective, efficient* and *engaging*, so much so that distance education is increasingly being seen as not only a viable mode of learning and teaching, but one that is equally effective, and highly regarded in terms of parity of esteem (see Bernard, Abrami, Lou, Borokhovski, Wade, Wozney, Wallet, Fiset, & Huang, 2004).

Although, in its excitement to embrace the Internet and the Web for bridging the distance between the learner and the teacher, it is arguable that distance education has in fact further

disenfranchised those it set out to empower especially the very large numbers of students in developing contexts who do not have access to reliable and affordable Internet service (see Baggaley, 2008).

A classic example of this is the concept of *cloud-based learning* which is built around the use of the Internet as the backbone for learning and teaching. It incorporates bringing together teachers and tutors over the Internet to help learners at a distance on the assumption that learners are self-organizing systems and capable of learning by themselves with the help of open educational resources, lots of encouragement and motivation, and a little bit of guidance (http://bit.ly/3dsj42).

Ironically, this is what the printed study materials sought to do in earlier iterations of distance education on the assumption that adult distance learners were highly motivated and independent learners. We found that while the printed study materials afforded flexibility to the learner, in terms of the time, place and pace of their study, it did not suit many who needed a bit more help over and above that, hence the surge to integrate a greater degree of interactivity with occasional face-to-face meetings in the distance learning and teaching transaction.

Currently though the technology that is being utilized to bring together the learners and their teachers and mediate the learning and teaching process is different. However, whereas, the printed technology did not exclude anyone, contemporary tools and infrastructure such as the Internet does, and large parts of the developing world still have no or unreliable, and inequitable access to the Internet. Without reliable, affordable and equal access to the Internet, online educational resources such as those developed and promoted by organizations such as the Khan Academy (see http://bit.ly/1e5kGyU) will run the risk of becoming an elitist educational provision that will remain inaccessible to those without the requisite tools and technologies.

4. Provision of two-way communication

A critical component of attempts to reunite and reconnect the distance learner, the teacher and the teaching organization without anyone moving physically has been the establishment of communication between the parties. The earliest forms of communication between distance learners and their teachers was

correspondence with letters delivered by the regular postal services, hence the use of term *correspondence education* to refer to the operation.

In most cases however, this was a tiresome and frustrating experience as in those early days in the mid-nineteenth century postal mail was slow and unreliable. Today however, the postal service is a lot more reliable and speedy. In addition, a whole suite of contemporary technologies, ranging from audio and video conferencing, online messaging and emailing to social media tools are available to support two-way and multiple-way communication between learners, teachers and the teaching organization, both synchronously and asynchronously.

These technologies, especially the Internet and Web are responsible for the exponential growth of online education, including our current fascination with Massive, Open, Online Courses (see Naidu, 2013b). They are also responsible for promoting the view that knowledge and understanding is the result of communication, discussion and debate, epitomised by the concept of *connectivism* and connective knowledge (see Downes, 2012; Milheim, 2013; Siemens, & Downes, 2011).

In so doing however, contemporary communications technologies invariably excludes all those who do not have access to reliable and affordable connectivity to the Internet, especially those in large areas of the developing world. Yet that is where education is most needed to bring about the kind of development and as a result of it, the kind of freedom that Sen is talking about (see Sen, 1999).

Has contemporary distance education gone wrong, and if so then where and how? (see Baggaley, 2008; Cooper, 2013). Perhaps there is no one size that fits all. Perhaps there ought to be different models of distance education for different purposes, contexts, and learners (see Baggaley, 2009).

5. Possibility of occasional meetings

Distance education methods did not set out to preclude face-to-face meetings completely, as long as most of the time there would be no need for the learners and teachers to be in the same place and at the same time. However, if the need arose, and if it were possible, then occasional face-to-face meetings would be

organized, and depending upon their purpose these meetings could be made optional, so that students would not be required to attend, if they could not, or chose not to attend.

The purpose of these occasional gatherings could be many and varied. They might include meeting for laboratory work requirements in the Sciences and Engineering, give oral presentations as might be required in Business and Law, but also to network, socialise, and build a sense of community generally to break the loneliness of the distance learner and the overall tyranny of distance.

The earliest iterations of *online* distance education adopted a similar approach. Even with constant online connectivity, online learners and teachers hungered for occasional physical meetings, and as in the case of print-based distance education, for all sorts of reasons including learning and teaching and socialization purposes, leading to the emergence of the concept of *blended learning*, which was really blending online education with occasional face-to-face meetings.

In the early days, this would include travelling by road or air to the designated venue at some significant cost to the student, both in terms of time and loss of income. Now of course, with the availability of advanced communications technologies such as audio and video conferencing, online meeting and social media tools, the ability of distance learners to meet virtually for socialization and building community is significantly improved. And developments in technologies for conducting laboratory work remotely are eliminating the need for face-to-face meetings in the study of subjects like engineering and architecture at a distance (Lindsay, Naidu, & Good, 2007).

6. Participation in an industrialised form of education

A final distinguishing feature of distance education is its adoption of industrial processes. In comparison with conventional educational practices which was characterised by the classroom lecture, tutorial and laboratory work, distance education appeared to look like an industrialised form of educational practice. This seemed like so, not only because of its progressive thinking in its use of technology for mediating learning and teaching and offering a choice to those who could not afford campus-based education, but more so because of its logistics which were characterised by

specialisation of tasks and the division of labor, as was the case in the industrialization of our economy during the 18th century (Peters, 1983).

In conventional educational practice, the teacher is the aggregate of all educational functions. This includes designing the course, teaching it, assessing student work and providing learners with feedback, as well as engaging in research and scholarship in their field. In distance education however, these functions are disaggregated and carried out by specialists in specific areas of design, development, distribution, support, and research and evaluation. Moreover, this course may be delivered by a whole range of people including full time, part time or adjunct faculty.

In an increasingly competitive tertiary educational environment, with declining public funding for higher education, distance education methods including the disaggregation of teaching functions especially from those of research and scholarship are being seen and adopted as a viable way forward by many conventional campus-based educational organizations (Gallagher, & Garrett, 2013). A compounding factor is the proliferation of information and communications technology which is requiring a variety of additional teaching skills and competencies that have to be developed by staff, over and above subject matter knowledge, in order to be effective and efficient.

It is becoming increasingly difficult for the teacher, who is usually the subject matter expert, and not a trained teacher but a researcher by training to perform all of these tasks effectively and efficiently in the one role. As a result, the aggregation of the various functions of teaching and research and professional engagement in academe in the one role is undergoing change, leading calls for its disaggregation as has always been the case in distance education (see Rosenbloom, 2011).

In conclusion

The current model of campus-based and face-to-face educational practice is increasingly becoming unsustainable, and there are many reasons for this. Foremost among these are the pressures that are at the heart of its funding model and the increasing availability of information and communications technologies that are opening up educational opportunities. There are many more

routes for accessing educational content today (see Gallagher, & Garrett, 2013).

As a response to this, it seems that after years of existing on the periphery and competing for parity, distance education methods are appealing to mainstream educational provision. Conventional campus-based educational organizations are adopting practices that were pioneered by distance education, not as a cheaper and poorer option, but as a sustainable and viable response to the pressures and demands facing the higher education sector.

In the early days of the invention of this nontraditional form of education, distance educators walked alone and on the periphery and looked in from the back door. Today we have the support of mainstream educational forces and the company of Ivy League institutions which is heartening. A new norm is emerging and it is opening up access to educational opportunity, as well as learning resources. It is time for us in the field of open, flexible and distance learning to rise up and seize the day and this opportunity -- and based on our track record, to lay claim on the movement to transform education at all levels, not just higher education.

In this region, the Open University of Sri Lanka is well placed to lead this movement to liberate education and make it available to all and to especially those who can least afford it. This is a serious responsibility that requires careful thought to selecting and adopting teaching methods and appropriate technologies that are best able to support teachers and their learners in the context within which they live and work.

You and the Open University of Sri Lanka have the experience and the expertise to lead this charge! So go forth in the knowledge that you are part of a progressive educational movement that is here to stay and is poised to significantly influence future educational practice more generally.

Congratulations on your achievements, and I wish you all well. God Bless!

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