Conference Proceedings
International Conference on Climate Change-2017
(ICCC 2017)

16th-17th, February, 2017

Colombo, Sri Lanka

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DIRECTOR'S MESSAGE, CLIMATE CHANGE SECRETARIAT

It is an honour and a privilege to deliver this message on behalf of the Climate Change Secretariat of the Ministry of Mahaweli Development and Environment for this important event of the International Conference on Climate Change 2017 organized by the International Institute of Knowledge Management and hosted by the University of Colombo, Sri Lanka. As most of us aware, one of the major challenges faced by the world community today is the rise of global warming mainly due to human activities. With the world population increase, it seems more pollution will be taken place. Hence it is undebatable that immediate actions have to be taken to control further rise of global warming due to unlimited targets.

During the last three decades, concerns have constantly been growing on climate change and its consequences. At the 21st session of Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) conducted in Paris in 2015 a decision was taken to act together as a global community to limit the rise of global warming below 2 degree Celsius by 2100. Additionally, the agreement aims to strengthen the ability of countries to deal with the adverse impacts of climate change.

Climate change is now inevitable and it will affect all systems, sectors and communities. Some of them may be highly vulnerable and some may be less vulnerable. However all sectors and communities must put an effort to build resilience over adverse impacts of climate change accordingly. There are many scientific researches going on regarding climate change and its various aspects all over the world. Intergovernmental Panel on Climate Change (IPCC) is the main institution where all these research information gathered and compiled for the future requirements. Even though there are many researches going regarding climate change in Sri Lanka, this information is scattered in many local and international research agencies. In addition quantitative climate change impact assessments, reliable forecasting are still hard to find. Therefore these areas should be particularly addressed in research fields.

At this juncture I must emphasise that climate change mitigation and adaptation will require close cooperation between scientific and development communities. This effort therefore is both timely and important. Finally I take this opportunity to express my sincere gratitude to International Institute of Knowledge Management and University of Colombo for their collaborative effort in organizing this conference and I wish a great success of this great event.

Dr. R.D.S. Jayathunga,

Director,

Climate Change Secretariat,

Ministry of Mahaweli Development and Environment,

Sri Lanka.

THE MESSAGE FROM THE CONFERENCE CHAIR

Climate change has become the most important environmental issue of the century, given the devastating impacts it has caused all over the world. Increased frequency of floods, heatwaves, droughts, and associated impacts can be heard not only from tropical islands like Sri Lanka, but also from land-locked countries or areas within such countries all around the world. The history since industrial revolution provides ample evidence for human interference with the earth's climate system mainly through increased rates of deforestation, fossil fuel burning, and various other activities, in fulfilling the ever-increasing needs of the humanity.

In dealing with climate change, international cooperation and knowledge sharing with regard to new developments in the field are essential, as no single nation alone can deal with the complicated impacts associated with this global issue. The Paris Agreement adopted at the 21st Conference of the Parties of the UNFCCC (COP21) held in Paris in 2015 aims at limiting the global average temperature rise during the century to well below 2 ^{0}C above pre-industrial levels by taking necessary action. The 1st International Conference on Climate Change 2017 (ICCC-2017) organized by The International Institute of Knowledge Management (TIIKM) will be held with the theme 'Climate Change, Facing the challenge beyond COP21', as there is a big challenge ahead of us in facing the impacts of climate change while trying our best to reach the above targeted emission reduction by the end of the century.

One of the key goals of the conference is creating dialogue among those involved in research and development activities in Climate Change Mitigation, Vulnerability, and Adaptation, nationally and internationally. As the Chair of the conference I hope this event will create continued dialogue during and beyond the ICCC-2017, with the participation of local and international scientists. Through this event, it is envisaged to share and disseminate information relevant to research and development experiences encompassing important areas such as vulnerability to the impacts of climate change on food security, biodiversity and natural resources, health and sanitation, developments in adaptation and mitigation research, and various other aspects such as greenhouse gas measurements, modelling and climate predictions, etc. It was a difficult task to select the abstracts for the conference from the large number of abstracts we received. I wish the presenters of selected abstracts, representatives of the universities, research institutes, and governmental- and non-governmental institutions, etc., including the young scientists to have a fruitful gathering benefitting towards the betterment of their future work.

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Climate Change: Biodiversity Conservation with Reference to Thar Desert

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Abstract:

The aim of this paper is to analyze the impact of climate change on biodiversity; study the conservation of biodiversity and implications of government policies in the study area. The pattern of current rainfall and temperature in the study area has unexpectedly changed. This paper focuses on the conservation of the species that reached the verge of extinction in the Thar Desert of Western Rajesthan, India.

The information relevant to climate change, degradation of biodiversity and conservation of Biodiversity were collected from state Weather Department and State Biodiversity Board, Government of Rajasthan, Jaipur, India. The information of rain rainfall and air temperature were collected from State Irrigation Department, Government of Rajasthan, Jaipur and the Research stations of Central Arid Zone, Research Institute of Bikaner, Jaisalmer, Jodhpur and Pali. The data was analyzed for long term changes using regression analyses.

According to the data from weather department of Rajasthan government the pattern of rainfall and temperature has been changed over the past 100 years. Many of the protected species of fauna and flora are on the verge of extinction; forested area is also decreasing in the area. The conservation of water has become the vehicle for the conservation of the biodiversity in the Thar Desert. The water in the Indira Gandhi canal command area, if used judiciously, may encourage biodiversity.

It was found that the awareness creation among people is very important for biodiversity conservation.

It is helpful to understand impact of climate on fauna and flora in conservation planning.

The maintenance and conservation of biodiversity is needed for human survival. People in Thar Desert have survived for ages with the application of their collective intelligence in conserving biodiversity.

Keywords: Thar Desert, climate change, biodiversity, variability

Introduction

By the end of 21st century the impact of climate change as projected by Inter Governmental panel on climate change (IPCC, 2007) is more likely on arid ecosystem than in semi-arid or sub-humid regions of India. Thar Desert in Rajasthan, spreading in twelve western districts of the state covering 19.61 million ha, is very fragile and subjected to excessive stresses due to frequent drought and low rainfall. Climate change results in shifting rainfall patterns, increased temperature, more demand for water and it can be a significant driver of biodiversity with changing life cycles, migration, loss and invasion of new habitats in Thar region. Biological diversity and climate are closely interconnected and each impacts the other. Biodiversity always builds natural resilience to climate extremes as forests are natures social security check in times of disaster and crisis, additionally forests also act as a sink for greenhouse gas emissions such as Carbon dioxide.

Rajasthan state is the largest state of India, where has areas of climate change sensitivity.

In the recent times the state has experienced severe and frequent spells of drought than any other region in India. According to the State Control Board the reason suffers from increased water shortage due to reduction in rainfall as well as increased evapo-transpiration due to global warming. These types of changes are directly responsible for the loss of biodiversity.

The desertification process may continue due to increased biological activity, as a result of over-grazing and loss of vegetation cover with consequent more radiant energy loss and reduction in convective activity (Sikka.1997). Soil degradation and loss of vegetation impact the thermodynamic balance in the north western India and expansion of Thar Desert due to this can lead to a pronounced and large scale impact on summer monsoon hydro climate of the north western region of India. (Bollasina and Nigam, 2011)

Western part of India is rich in biological diversity with arid climatic conditions of the region suitable for adaptation of different species in the TharDesert. There are extreme weather conditions such as low rainfall, high temperatures, strong winds as well as low humidity making it inhospitable to different habitats leading to animal migration and loss of their habitats within the Thar region (Rao, 1992; 2005; 2009). The objectives of this research are to analyze the impact of climate change on biodiversity in the Thar Desert, study the status of conservation of biodiversity, study implication of government policies in Thar Desert to conservation of biodiversity, and study the level of environmental awareness among the people.

Study Area
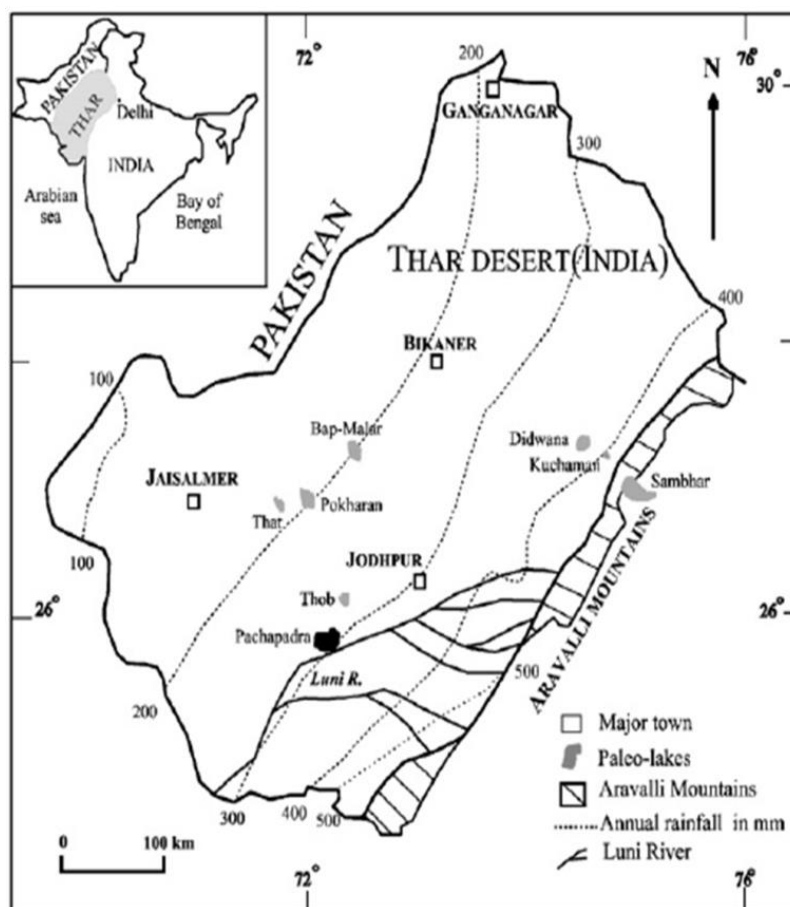
Figure: 1. Map of the study area

The study area is located in Western Rajasthan covering around 2% of the land of Jaisalmer, Barmer, Bikaner and Jodhpur district; it is a part of the Thar desert spread over 446,000 sq. km on both sides of Indo-Pak border covering the southern part of Haryana, Punjab and province of Pakistan. Bounded by River Sindh in the West, River Sutlej in the northwest, the Aravalli range in the east, and the salty marshes of the Rann of Kutch in the South, the study area extends over 208, 110 sq. km. Climatically, it is hot and dry rainfall is scanty. Its physical build is however not so uniform; there are sand dunes, plains, hills, and salty marshes, etc. Luni is the only river that meanders through the desert and reaches the Arabian Sea through the Rann of Kutch; it is said to be the remnant of river Saraswati along which Vedas, the first written books of the world, were composed. Apparently, what is scrubland today was full of lush vegetation once upon a time. 300 million years ago, the dinosaurs and their ascendants roamed in this part of India.

Methodology

The information relevant to climate change, degradation of biodiversity and conservation of Biodiversity were collected from state Weather Department and State Biodiversity Board, Government of Rajasthan, Jaipur, India. The information of rain rainfall and air temperature were collected from State Irrigation Department, Government of Rajasthan, Jaipur and the Research stations of Central Arid Zone, Research Institute of Bikaner, Jaisalmer, Jodhpur and Pali. The data was analyzed for long term changes using regression analyses.

Variation in rainfall

Thar Desert covered twelve arid districts in the western part of Rajasthan. This region constitutes 61% of India area of India hot arid zone, where the annual rainfall varies from 100mm in the extreme, west to 400mm

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towards eastern part of the study area. The coefficient of annual rainfall varies from 40% in the eastern and 70% in western part of the Thar region, causing larger inter-annual variability in rainfall influencing crop production; the drought has affected crop as well as fodder production. Bikaner district experienced severe agricultural drought in 24% of the years and moderate drought in 26% of the years, whereas, Jodhpur district experienced severe drought in 18% of the years and moderate drought in 29% of the years, showing its variation in rainfall pattern due to climate change.

According to the present study, the overall regional annual rainfall (1911-2011) for Thar showed no significant rise (0.56 mm/year) in the rainfall. The rainfall trend at different locations showed that the annual rainfall is likely to change by +100 mm at Bikaner, +124mm at Jaisalmer, -40mm at Jodhpur and +21 mm at Pali. Long- duration crops like pearl millet, Sorghum are likely to be replaced with short duration and traditional crops like cluster bean, moth bean and gram where rainfall is expected to decrease in 21st century (Rao and Purohit, 2009). To cope up with the delayed monsoon conditions, crop contingency plans (Joshi and Amalkar, 2009) should be adopted.

Biodiversity of Thar Desert:

Thar Desert is not all sand; there are hillocks and sandy as well as grow plains too. This diversity in habitat has given rise to more diversity in vegetation, animal life and human culture in comparison to the other desert regions of the world. Trees are few ; but thorny bushes and shrubs in small patches are scattered all over the region. The main tree species found here are *Acacia*, *milotica*, *tamarix aphylla*, *prosopis cineraria* (Khejri). The dominant scrubs are *calligonum polygonoides*, *crotalaria Spp*, and *Haloxylon recurvum*. Among the xerophilious grasses of the region are *Aristida adscensionis*, and *Cenchrus biflorus*.

The desert of Rajasthan contains 25 species of serpents and 23 species of lizards. The endangered Great Indian Bustard, the Black buck, Indian wild ass and the Indian Gazelle are found here.

Out of the above species, some species like the great Indian bustard are being affected by climate change as well as human causes.

Major findings in relation to climatic change

The Northern part of India is expected to be warmer than the southern part of the country. The summer monsoon rainfall in India will increase and extreme rainfall events would rise sharply. The rainfall trend during the last 100 years revealed that the summer monsoon rainfall, which contributes more than 85% of the total annual rainfall in the region, has increased marginally (<10%) in the South and East part of the Thar Desert, but has already declined by 10-15% in its north-western part of India. Earlier studies on changes in rainfall and air temperatures of north-west part of India showed that the rainfall increased marginally by 141 mm in the past 100 years (Pant and Hingane, 1988), especially in the irrigated belt of Ganganagar region particularly during the past 3 decades (Rao, 1996)

Conservation of Biodiversity

Biodiversity can be conserved in two ways: ex-situ (i.e. out of the natural habitat) and (in-situ within the natural habitat) conservation.

In-situ conservation maintains the genetic diversity of the species; at the same time it helps the species to adapt to the changing environment caused by nature or anthropogenic activities. It also helps in preservation of other related species of the habitat. For this type of conservation technique certain area are designated as protected sites. It is being promoted by the man and Biosphere (MAB) program of the United Nations educational, scientific and cultural organization (UNESCO).

The ex-situ methods of biodiversity conservation include creation of zoos where captive breeding programs are carried out; development of aquaria for research, public information and education; and plant collections

through seed storage and breeding. Zoos are not just public display facilities and for educating people about wild animals, but are also for captive breeding specially of the vertebrates such as panda and dormouse that are facing extinction.

There are a number of biodiversity conservation sites in Indian desert. The most important and by for the largest among them is Desert National Park, Jaisalmer. It spreads over 3162 km^2, and it is an excellent example of the ecosystem of the Thar Desert, and its diverse fauna. Among the measures being adopted to conserve and preserve the plant life in Indian desert is greening of the desert.

The scientists of Central Arid Zone Research Institute (CAZRI), have successfully developed and improved dozens of traditional and non-traditional crop/fruit plants that produce much larger fruits than before where can thrive with minimal rainfall. Arid Forest Research Institute (AFRI) situated at Jodhpur, has carried out scientific research in forestry on order to provide technologies to increase the vegetative cover and to conserve the biodiversity in the hot arid and semi-arid region of Rajasthan .

In the Thar Desert agriculture is not a dependable proposition because after the rainy season, at least one third of crops fail. Animal husbandry, with trees and grasses, intercropped with vegetables or fruit trees, is the most viable model for arid, droughts-prone regions. The region faces frequent droughts and overgrazing due to high animal populations, wind and water erosion, mining and other industries have resulted in serious land degradation. In this desert region of Rajasthan is a major opium production and consumption.

The Thar Desert is one of the most heavily populated desert areas in the world with the main occupations of its inhabitant's agriculture and animal husbandry. Animal husbandry is the major livelihood in the Thar Desert. Livestock depends for grazing on common lands in villages. During famine years in the Desert the nomadic rebari people move with large heards of sheep and camel to the forested areas of south Rajasthan.

Concluding Remarks

The Thar Desert region is a very sensitive region to changing global climate. Development of strategies, adaptation of traditional knowledge and practices related to biodiversity conservation and sustainable use along with modern scientific interventions will lead to mitigation of adverse effects of anticipated climate change on biodiversity in Thar Desert region.

The present government policies on biodiversity conservation are not working well. Many of the protected species of wild life are on the verge of extinction and forests are decreasing in area as the pressure of variability of rainfall and temperature pattern as well as population on land increases. The stage has come, when each village and city should be asked to reserve at least 20 percent of its land for forests. It may be that several villages can join hands and have joint forests reserves along the rivers on the hills and other areas not used for agriculture. Some of the less productive areas can be devoted to forestry. This may not be a very feasible proportion in states like Rajasthan when climatic restrictions affect forestry.

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Estimation of Asian and Global Carbon Fluxes Using Maximum Likelihood Ensemble Filter (MLEF)

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Abstract:

Purpose: CONTRAIL (Comprehensive Observation Network for Trace gases) observations retrieved by passenger aircrafts is becoming more popular among the researchers who are doing inverse modelling. The inverted Asian CO_2 fluxes still remains challenging with a large uncertainty due to lack of observations. In this study, we use maximum likelihood ensemble filter (MLEF) method to estimate the carbon fluxes using CONTRAIL observations in addition to the existing flask and continuous measurements.

Methodology: A pseudodata experiment is carried out with the artificially generated biases for the CO_2 fluxes. Hourly land fluxes (Net Ecosystem Exchange (NEE)) derived from Simple Bioshere-version 3 (SiB3) model, Takahashi ocean fluxes and Brenkert fossil fuel emissions are the fluxes used. Estimated fluxes defined in monthly scale are recovered for the months from May to October using MLEF coupled with Parametric Chemistry Transport Model (PCTM).

Findings: CONTRAIL observations give a considerable uncertainty reduction for the estimated land fluxes for the Asian region and more than 50% uncertainty reduction for North American and European regions. Pseudo truth has been well recovered using this assimilation scheme.

Originality: In the future, this model is going to be used with real observations to identify the carbon sinks and sources globally as well as mainly for the South Asian region.

Keywords: ensemble data assimilation, Maximum Likelihood Ensemble Filter, CONTRAIL data, Asian region

Introduction

Climate change is a critical environmental issue closely linked with the increase of greenhouse gases in the atmosphere. Among greenhouse gases, CO_2 plays the main role in greenhouse effect.

Inverse modelling has been used to quantify the spatial and temporal variations of sources and sinks of CO_2. The spatial and temporal distribution of CO_2 fluxes provides more information about the global carbon cycle, which has been analyzed using inverse methods to estimate regional sources and sinks. The literature is rich on inverse modelling and several applications to CO_2 fluxes are Tans et al., 1990; Gurney et al., 2002; Rodenbeck et al., 2003; Michalak et al., 2004; Bruhwiler et al. 2005; Peters et al. 2005; Zupanski et al. 2007a; Lokupitiya et al. 2008; "Carbon Tracker", 2011; Niwa et al. 2012; Jiang et al. 2014; Zhang et al. 2014; Thompson et al. 2016.

During past two decades, greenhouse gas emissions from Asian countries have also been increasing rapidly particularly due to industrialization and population growth. Asia is an important region for the global carbon

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budget and it is the 4th of the world's 10 largest national emitters of CO_2 (Thompson et al., 2016). Therefore, it is vital to estimate the CO_2 fluxes with high precision for the Asian region. Many efforts have been carried out to estimate the Asian terrestrial carbon sources and sinks using inverse modelling. But the inverted Asian CO_2 fluxes using inverse modelling still remains challenging with a large uncertainty due to lack of observations (Patra et al., 2012, 2013; Piao et al., 2012; Jiang et al., 2013; Zhang et al.,2014). A comparison study of carbon flux inversions by Peylin et al. (2013) has shown that there is more consistency between inversions for larger scales and for the regions where the atmospheric network is denser, as expected. Those studies highlighted the importance of the collecting more CO_2 observations using new methods in order to achieve good estimates for the CO_2 fluxes. Niwa et al. (2012) has mentioned that the lack of measurements at the surface can be partially compensated by satellite observations and increasingly by aircraft measurements in the free troposphere.

Newly available, CONTRAIL (Comprehensive Observation Network for Trace gases) observations by Airliner using passenger aircraft is becoming more popular among the researchers who are doing inverse modelling. CONTRAIL aircraft project provides CO_2 mole fractions using on-board passenger flights since 2005 and has produced a large coverage of in situ CO_2 data ranging over various latitudes, longitudes and altitudes (Machinda et al., 2008). Compared to research aircrafts, passenger aircraft CO_2 measurements are done at a much lower cost and could cover larger areas. The CONTRAIL project measures CO_2 continuously between Japan and Europe, Australia, South and Southeast Asia, and North America (Jiang et al., 2014). CONTRAIL CO_2 measurements have been used in an inversion system for the first time by Niwa et al. (2012) to identify the areas of greatest impact in terms of reducing flux uncertainties. Patra et al. (2011) and Zhang et al. (2014) also successfully used CONTRAIL measurements to estimate surface CO_2 fluxes.

In this study, we used ensemble based method called maximum likelihood ensemble filter (MLEF) (Zupanski et al., 2005; Zupanski and Zupanski et al., 2006, Lokupitiya et al., 2008) to estimate the carbon fluxes for the South Asian Region using the CONTRAIL observations in addition to the existing flak and continuous measurements. Similar to the pseudodata experiment done by Lokupitiya et al. (2008), we conducted a pseudodata experiment to test the performance of MLEF on estimating the carbon fluxes by assimilating CONTRAIL measurements, which mainly cover the Asian region.

This paper consists with four sections. Section 2 describes the data assimilation method used in this study. Results based on the pseudodata experiment is given in Section 3. The final section, Section 4 gives the conclusion and discussion with future work of the study.

Methodology

Lokupitiya et al. (2008), has been successfully carried out a pseudodata experiment by using the MLEF method, coupled with a global atmospheric transport model to estimate the global CO_2 fluxes at regional scale with an existing observation network that includes flask, aircraft profiles and continuous measurements. The MLEF has been developed by incorporating ideas from variational methods, iterated Kalman filters and ensemble transform Kalman filter. A cost function is minimized numerically, which allows one to incorporate nonlinear models if necessary. MLEF incorporates iterative minimization of a non-linear cost function with advanced Hessian preconditioning, which makes it more robust for non-linear processes. The method is based on maximum likelihood (rather than minimum variance) estimation and thus the optimal solution is given by the mode (rather than the mean) of the posterior distribution (Lokupitiya et al. 2008).

Data Assimilation Scheme

Hourly land fluxes (Net Ecosystem Exchange (NEE) = Respiration (RESP) – Gross Primary Productivity (GPP)) derived from Simple Bioshere-version 3 (SiB3) model (Baker et al., 2003; 2007), Takahashi ocean fluxes (Takahashi et al., 2002) on a monthly time scale and Brenkert fossil fuel emissions (Brabkert (1998)) are

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the fluxes used. The mid monthly values of the ocean fluxes are interpolated to hourly time resolution in order to be consistent with the hourly land fluxes.

In this study, the fluxes are estimated by optimizing the unknown biases added to each flux component. Bias term for the fossil fuel emission was not considered due to the low variations of the fossil fuel emissions within a year. Biases are defined at 10^0 longitude by 6^0 latitude spatial resolution. The biases added to the NEE and air-sea gas exchange are estimated using the MLEF data assimilation method.

Mathematical representation of the optimization problem is given as follows:

$$F(x,y,t) = (1+\beta_{NEE}(x,y))\times NEE(x,y,t) + (1+\beta_{ocean}(x,y))\times Ocean(x,y,t) + FF(x,y,t), \tag{1}$$

where $NEE(x,y,t)$, $Ocean(x,y,t)$ and $FF(x,y,t)$ are the fluxes from land, ocean and fossil fuel emissions at the x, y spatial coordinates and time t, which is at hourly resolution. Slowly varying biases defined in monthly scale are recovered by estimating those for the months from May to October using MLEF coupled with Parametric Chemistry Transport Model (PCTM). Since there are few number of CONTRAIL observations for the first few months of the selected year, data assimilation was started from May. Number of data assimilation cycles had to be limited to six in order to save the time to complete the experiment due to computational restrictions on available resources. The transport model is run at 2.5^0 longitude and 2^0 latitude spatial resolution with 25 vertical levels.

To examine the impact of CONTRAIL data on flux estimates, pseudodata experiment was conducted and the uncertainty reduction of the biases were compared by carrying out two experiments with and without CONTRAIL data for the selected time period. The selected year for the experiment is year 2006. The size of the data assimilation window is 4 weeks and the biases are assumed to stay constant throughout this 4 week time period. At the starting point of the data assimilation (first data assimilation cycle) we used unbiased case (β_{NEE} = β_{ocean} = 0) at every grid point. This is called as the background or first guess. Prior uncertainties (standard deviations) are selected as 0.4 and 0.2 for land and ocean priors. The selection of the prior uncertainties for the biases is very important in inverse modelling. Selection of larger prior uncertainties may allow more freedom for the biases to move, which may prevent reaching a reasonable solution when the observation network has few number of observations. Smaller prior uncertainties may lead biases to get stuck in a wrong solution (Lokupitiya et al., 2008).

The fist guess vector along with the perturbed background vectors (ensemble members) was used to compute the hourly CO_2 fluxes using equation (1). For this experiment, we use 90 ensemble members. The created hourly CO_2 fluxes under each ensemble member was run through the transport model for 4 weeks (data assimilation window) to simulate CO_2 concentrations at the observation sites. Then the optimized β were obtained by minimizing the distance between the simulated and observed CO_2 concentrations using the method of MLEF. In each subsequent cycle, the average of posterior from the previous cycle and prescribed values from the initial cycle was considered as the prior. This was done for both mean and the uncertainty of the biases.

Observations

Three types of observations are used for the data assimilation. Those are 59 CMDL surface flask observations that are collected on weekly basis, 32 continuous sites that are measured in-situ at different vertical levels on an hourly basis and CONTRAIL aircraft locations on hourly basis. Observation locations and site names for flask and continuous sites are given in Figure 1 and Table 1. There are very few number of flask and continuous sites over the Asian region. But CONTRAIL observations increase the observation number in those regions. For the year 2006, CONTRAIL aircraft tracks are plotted in Figure 1. It does not include all the CONTRAIL locations for year 2006 as the location file used for this pseudodata experiment was from May to October.

Observation error is the most important part in inverse modelling method. It should be pre-defined in the inverse modelling framework. It is the sum of the instrument, representation (error due to scale mismatch between the observations and the transport model) and forward model errors. In this pseudodata experiment, a random error term was added by assuming that the observation errors follows a normal distribution with zero mean and standard deviation of one. On average 2ppm (parts per million) error was assumed for each data point.

But for the real data experiment, the observation errors (model-data mismatch) have to be calculated using the true concentrations and the simulated concentrations which can be obtained from the transport model. Also, for the continuous sites, uncertainty has to be added according to the local time and station height as used in Lokupitiya et al. (2008). In observation error covariance matrix (R), observation errors are represented by the diagonal elements of the matrix. In this experiment, we assume that the observation errors are uncorrelated in between the observation stations. That is the observation stations are far from each other.

Pseudodata

Pseudo truth was calculated by using monthly varying artificially generated bias maps for the flux components. Pseudo CO_2 concentrations were created by running the transport model forward for three years (3-year spin-up) and then sampled the CO_2 concentrations at the observation locations in the fourth year by running the model with the biased fluxes. Each observation was perturbed by adding an error term generated randomly. At the end of the third year, 3D model state was saved and those were used as the true CO_2 concentrations for the data assimilation scheme.
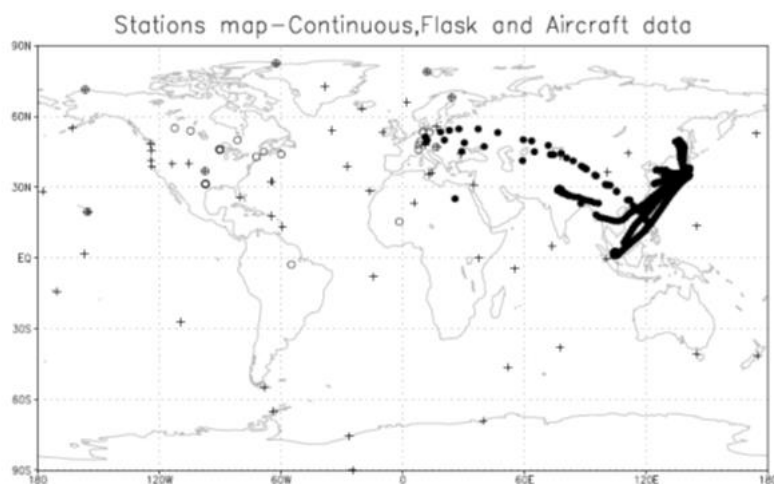

Fig. 1.   A map of the stations used and CONTRAIL aircraft tracks for year 2006.
Open circles - continuous measurement sites, Crosses - flask sampling stations (NOAA-ESRL network),
Solid circles - CONTRAIL data - Provided by Dr. Prabir Patra, Senior Scientist, Research Institute of Global Change, JAMSTEC, Japan.

Table 1 Names of the flask and continuous sites

Code	Name	Lat (°)	Lon (°)	Alt /Height(m)
Flasks:				
ALT	Alert, Nunavut, Canada	82.45	-62.52	0.
AMS	Amsterdam Island, Indian ocean (France)	-37.95	77.53	0.
ASC	Ascension Island, UK	-7.92	-14.42	0.
ASK	Assekrem. Algeria	23.18	5.42	2728
AVI	St. Croix, Virgin Islands, USA	17.75	-64.75	0.
AZR	Terceira Island, Azores, Portugal	38.77	-27.38	0.
BAL	Baltic Sea, Poland	55.50	16.67	0.
BHD	Baring Head Station, New Zealand	-41.42	174.87	0.
BKT	Bukit Kototabang, Indonesia	-0.20	100.32	0.
BME	St. Davis Head, Bermuda, UK	32.37	-64.65	0.
BMW	Tudor Hill, Bermuda, UK	32.27	-64.88	0.
BRW	Barrow, Alaska, USA	71.32	-156.60	0.
BSC	Black Sea, Constanta, Romania	44.17	28.68	0.
CBA	Cold Bay, Alaska, USA	55.20	-162.72	0.
CGO	Cape Grim, Tasmania, Australia	-40.68	144.68	0.
CHR	Christmas Island, Republic of Kiribati	1.70	-157.17	0.
CMO	Cape Meares, Oregon, USA	45.48	-123.97	0.
CRZ	Crozet Island, France	-46.45	51.85	0.
EIC	Easter Island, Chile	-27.15	-109.45	0.
GOZ	Dwejra Point, Gozo, Malta	36.05	14.18	0.
GMI	Mariana Island, Guam	13.43	144.78	0.
HBA	Halley Station, Antarctica, UK	-75.58	-26.50	0.
HPB	Hohenpeissenberg, Germany	47.80	11.02	0.
HUN	Hegyhatsal, Hungary	46.95	16.65	0.
ICE	Storhofdi, Vestmannaeyjar, Iceland	63.25	-20.15	0.
IZO	Tenerife, Canary Islands, Spain	28.30	-16.48	2360
KCO	Kaashidhoo, Republic of Maldives	4.97	73.47	0.
KEY	Key Biscayne, Florida, USA	25.67	-80.20	0.
KUM	Cape Kumukahi, Hawaii, USA	19.52	-154.82	0.
KZD	Sary Taukum, Kazakhstan	44.45	77.57	0.
KZM	Plateau Assy, Kazakhstan	43.25	77.88	1262
LMP	Lampedusa, Italy	35.52	12.62	0.
MHD	Mace Head, County Galway, Ireland	53.33	-9.90	0.
MID	Sand Island, Midway, USA	28.22	-177.37	0.
MKN	Mt. Kenya, Kenya	-0.05	37.30	3897
MLO	Mauna Loa, Hawaii, USA	19.53	-155.58	3397
NWR	Niwot Ridge, Colorado, USA	40.05	-105.58	1541
OPW	Olympic Peninsula, Washington, United States	48.25	-124.42	0.
PAL	Pallas-Sammaltunturi, GAW Station, Finland	67.97	24.12	0.
PSA	Palmer Station, Antarctica, USA	-64.92	-64.00	0.
PTA	Point Arena, California, USA	38.95	-123.73	0.
RPB	Ragged Point, Barbados	13.17	-59.43	0.
SEY	Mahe Island, Seychelles	-4.67	55.17	0.
SGP		36.80	-97.50	0.
SHM	Shemya Island, Alaska, USA	52.72	174.10	0.
SMO	Tutuila, American Samoa	-14.25	-170.57	0.
SPO	South Pole, Antarctica, USA	-89.98	-24.80	0.
STC	Ocean Station C, North Atlantic Ocean, USA	54.00	-35.00	0.
STM	Ocean Station M, Norway	66.00	2.00	0.
SUM	Summit, Greenland	72.58	-38.48	470
SYO	Syowa Station, Antarctica, Japan	-69.00	39.58	0.
TAP	Tae-ahn Peninsula, South Korea	36.73	126.13	0.
TDF	Tierra Del Fuego, La Redonda Island, Argentina	-54.87	-68.48	0.
THD	Southern Great Plains, Oklahoma, United States	-41.05	-124.15	0.
UTA	Wendover, Utah, USA	39.90	-113.72	0.
UUM	Ulaan Uul, Mongolia	44.45	111.10	0.
WIS	Sede Boker, Negev Desert, Israel	31.13	34.88	0.
WLG	Mt. Waliguan, Peoples Republic of China	36.29	100.90	0.

ZEP	Ny-Alesund, Svalbard, Norway and Sweden	78.90	11.88	0.
Continuous Sites:				
ALT	Alert, Nunavut, Canada	82.45	-62.52	30.
AMT	Argyle, Maine, USA	45.03	-68.68	107.
SGP	Southern Great Plains, Oklahoma, USA	36.61	-97.49	25.
CDL		53.87	-104.65	20.
FRS		49.88	-81.57	20.
HRV	Harvard Forest, Massachusetts, USA	42.90	-72.30	30.
LEF	Park Falls, Wisconsin, USA	45.92	-90.27	Multiple
SBI		43.93	-60.00	5.
WKT	Moody, Texas, USA	31.32	-97.32	Multiple
WPL		55.00	-112.50	9.
MHD		53.32	9.88	0.
HEI		49.40	8.70	0.
HUN	Hegyhatsal, Hungary	46.95	16.65	115.
BRW		71.32	-156.60	11.
TPJ		-2.86	-54.96	50.
PLS		67.97	24.12	565
ZEP		78.90	11.88	0.
NGL		53.17	13.30	0.
PLR		45.93	7.70	2601
SSL		47.92	7.92	326.
MLO		19.53	-155.58	3397.
MAL		15.30	-1.74	100.

Transport Model

Inverse modelling methods for carbon fluxes require a transport model to produce 3-D CO_2 fields, from which we sample the CO_2 at the location and times of the observations. This approach is limited by the accuracy of the numerical transport model, the circulation/wind inputs that derive the transport and the observational CO_2 data (Kawa et al., 2004). The transport model serves as the observation operator in the assimilation scheme and it performs the necessary interpolations and transformations from the state variable to the observation space. As in Lokupitya et al. (2008), Parametrized Chemistry Transport Model (PCTM) (Kawa et al., 2004) driven by assimilated weather data from the GEOS-4 (Goddard Earth Observation System, version 4) reanalyse was used as the observation operator for this experiment. The PCTM was run at 2.5^0 longitude by 2.0^0 latitude horizontal resolution with 25 vertical levels. The model integration time was 15 minutes, which was consistent with the spatial resolution.

MLEF

The MLEF coupled with the PCTM (Zupanski M., 2005; Lokupitiya et al., 2008) is the main theoretical framework applied in this study. MLEF method is described briefly here. MLEF finds the maximum likelihood state solution employing an iterative minimization of a cost function. In Bayesian data assimilation, the cost function is optimized and it can be defined as follows.

$$C(\boldsymbol{\beta}) = \frac{1}{2}[\boldsymbol{y} - H(\boldsymbol{\beta})]^T R^{-1}[\boldsymbol{y} - H(\boldsymbol{\beta})] + \frac{1}{2}[\boldsymbol{\beta} - \boldsymbol{\beta_b}]^T P_f^{-1}[\boldsymbol{\beta} - \boldsymbol{\beta_b}], \tag{2}$$

where **y** is a vector of observations of dimension equal to number of observations (N_{obs}), H is an observation operator, **β** is a vector of unknowns which is the state vector we are solving for (given in equation (3)), **β_b** is the prescribed prior estimate, R is the observation error covariance matrix with the size $N_{obs} \times N_{obs}$ and it includes instrumental and representativeness errors, and P_f is the prior error covariance matrix.

$$\boldsymbol{\beta} = \begin{pmatrix} \boldsymbol{\beta}_{NEE} \\ \boldsymbol{\beta}_{ocean} \end{pmatrix} \tag{3}$$

In the cost function, first part controls the difference between observations and second part constrains the solution by an a priori flux distribution. The solution for the state vector β is obtained by minimizing the cost function in equation (2). The solution for a state vector of dimension N_{state} is obtained by minimizing the above cost function by assuming a linear observation operator as follows.

$$\hat{\boldsymbol{\beta}} = \boldsymbol{\beta}_b + PH^T(HPH^T + R)^{-1}(y - H\boldsymbol{\beta}_b)$$

(4)

$$P_{\hat{\beta}} = P - PH^T(HPH^T + R)^{-1}HP$$

(5)

where $\hat{\beta}$ is the posterior estimate of the state vector **β** and $P_{\hat{\beta}}$ is its corresponding posterior covariance (Tarantola, 1987). The minimization is done using an iterative conjugate-gradient algorithm, which converges in a single iteration to the Kalman filter solution given in equation (4) when H is a linear function and the ensemble size equal to the size of the control variable.

Results

Uncertainty reduction of the land and ocean fluxes, comparison of the truth and the recovered land fluxes and comparison of the truth and the recovered land fluxes with their relevant standard deviations for the TransCom regions are discussed under the results.

Uncertainty reduction

In order to identify the effect of CONTRAIL observations for surface flux estimation, the pseudodata experiment was conducted separately with and without the CONTRAIL observations. Uncertainty reduction maps for land fluxes (Net Ecosystem Exchange) and ocean fluxes are given in Figure 2. Uncertainty reduction was calculated as in Equation 6.

$$Percentage\ of\ uncertainty\ reduction$$
$$= \frac{(Prior\ uncertainty - Posterior\ uncertainity)}{Prior\ uncertainty} \times 100$$

(6)
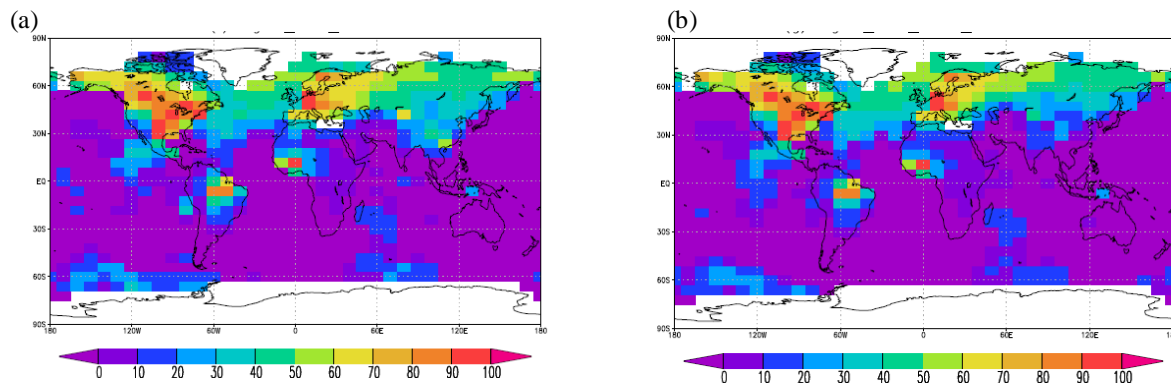
Fig. 2.   Uncertainty reduction maps for land fluxes   and ocean fluxes with (a) and without (b) CONTRAIL observations.

Higher uncertainty reduction (more than 50%) of estimated land fluxes can be observed in the North American and European regions due to the plenty of observation sites in those regions. Uncertainty reduction for the ocean fluxes is very low because of the weaker signal from the ocean fluxes to the observation sites. Also, a very low uncertainty reduction can be observed for the sparsely observed land regions. Considerable change of the uncertainty reduction of the land fluxes can be seen in Asian and European regions with added CONTRAIL observations. Figure 3 focuses on the uncertainty reduction of land fluxes for the Asia with CONTRAIL observations.
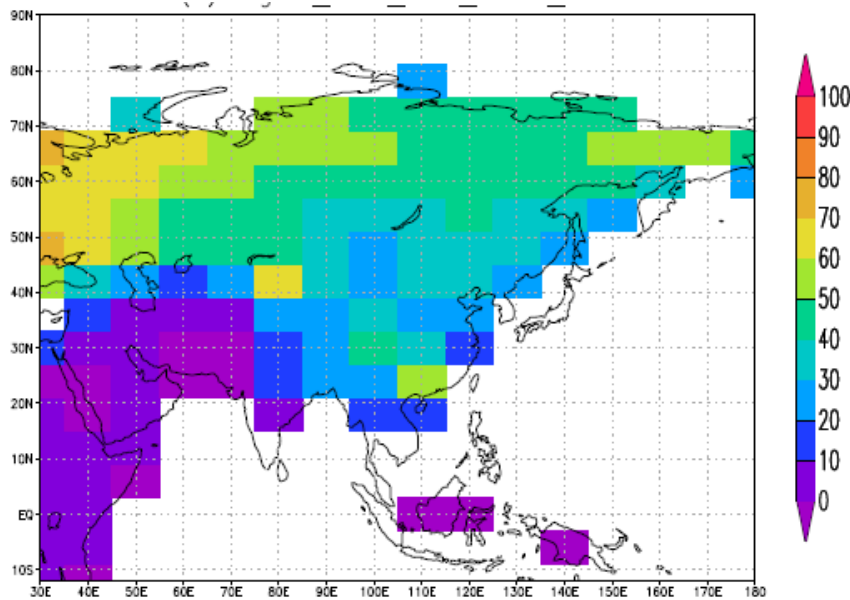
Fig. 3.   Uncertainty reduction map for the Asian region with CONTRAIL observations

Difference between the uncertainty reductions of the land fluxes due to the CONTRAIL observations is given in Figure 4. It clearly shows the considerable uncertainty reduction in Tropical Asia and Eurasian temperate due to CONTRAIL effect. For Tropical Asia, the maximum uncertainty reduction is in between 45% - 47.5% and for Eurasian Temperate it is in between 32.5% - 35%.
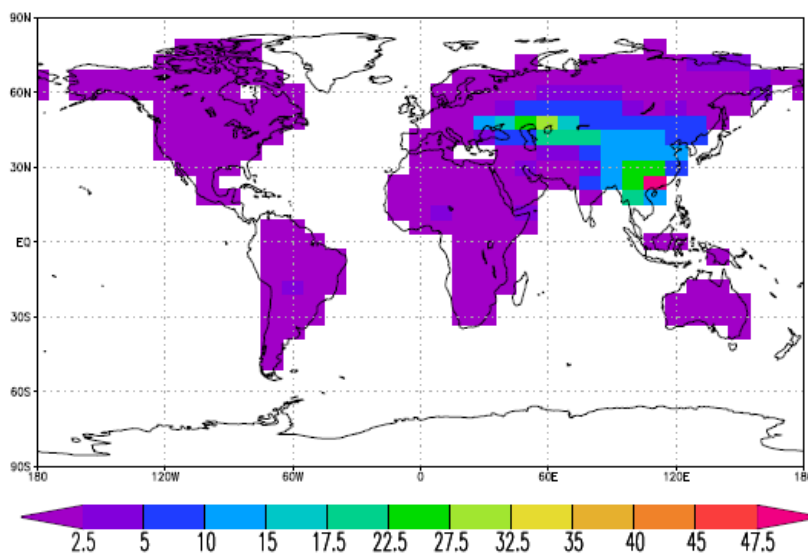
Fig. 4.   Change of the uncertainty reduction (%) due to CONTRAIL data.

According to Figure 3 and Figure 4, it can be said that the additional CONTRAIL CO_2 observations includes an extra constraint that can help to reduce the uncertainty on the inverted Asian and Eurasian CO_2 fluxes.

Comparison between recovered and the true fluxes

Pseudo truth and the recovered mean fluxes for the months from May to October for NEE are shown in Figure 5, (a) and (b) with CONTRAIL CO_2 observations.

(a)   (b)
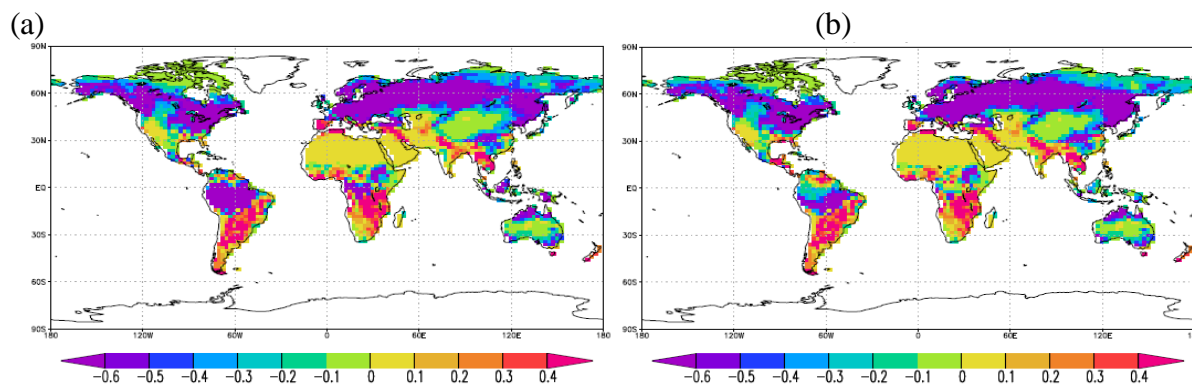
Fig. 5.   Pseudo truth (a) and the recovered (b) mean land fluxes (NEE). Units are in moles/m2/s

According to the Figure 5, a better agreement can be observed in between the recovered land fluxes and the truth except for the South American Tropical. The observation network of this study consists with only one observation site over the South American Tropical region. The assumed observation error may be not enough to capture the variations of observations around this region. Difference between the recovered fluxes from the two experiments that is the experiment run with CONTRAIL observations and without CONTRAIL observations are in Figure 6.
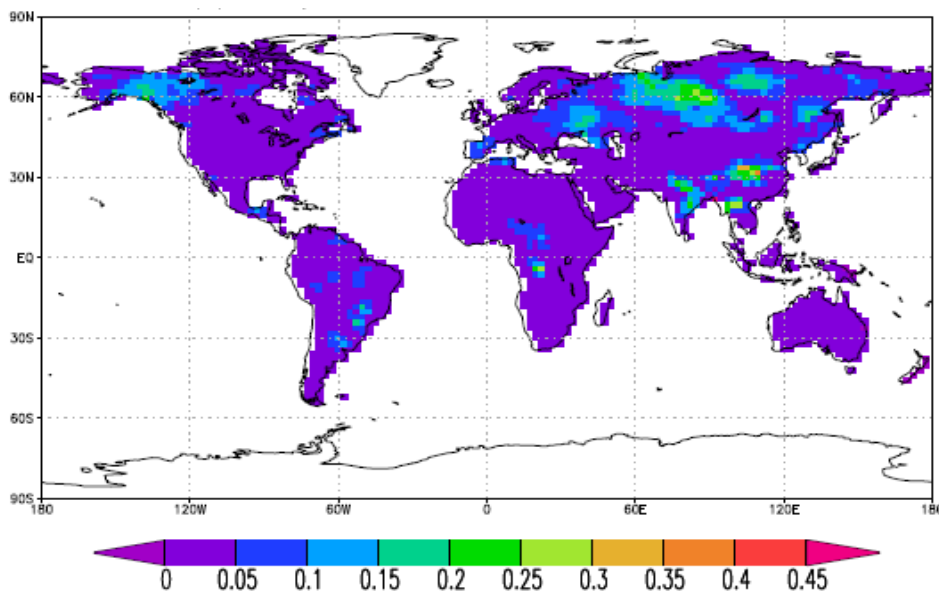
Fig. 6.   Change of the recovered mean land fluxes (NEE) due to CONTRAIL data. Units are in moles/m2/s

Effect of the CONTRAIL observations on the recovered land fluxes shows a considerable change for Europe, Asia and North American Boral.

Pseudo truth, recovered mean land fluxes with and without using CONTRAIL observations for the TransCom regions are given in Figure 7, (a). Except for the South American Tropical, recovered mean land fluxes show better agreement with the pseudo truth.

Pseudo truth, recovered land fluxes with and without using CONTRAIL CO_2 data with their relevant standard error bars are plotted for several TransCom regions are given in Figure 7, (b) and (c). South American Tropical, Eurasian Temperate and Tropical Asia show higher standard error values for the recovered mean land fluxes under both experiments. But the standard error values of the recovered land fluxes are low values for the Eurasian temperate and Tropical Asian regions, when the observation vector has CONTRAIL CO_2 observations.

(a)

(b)

(c)
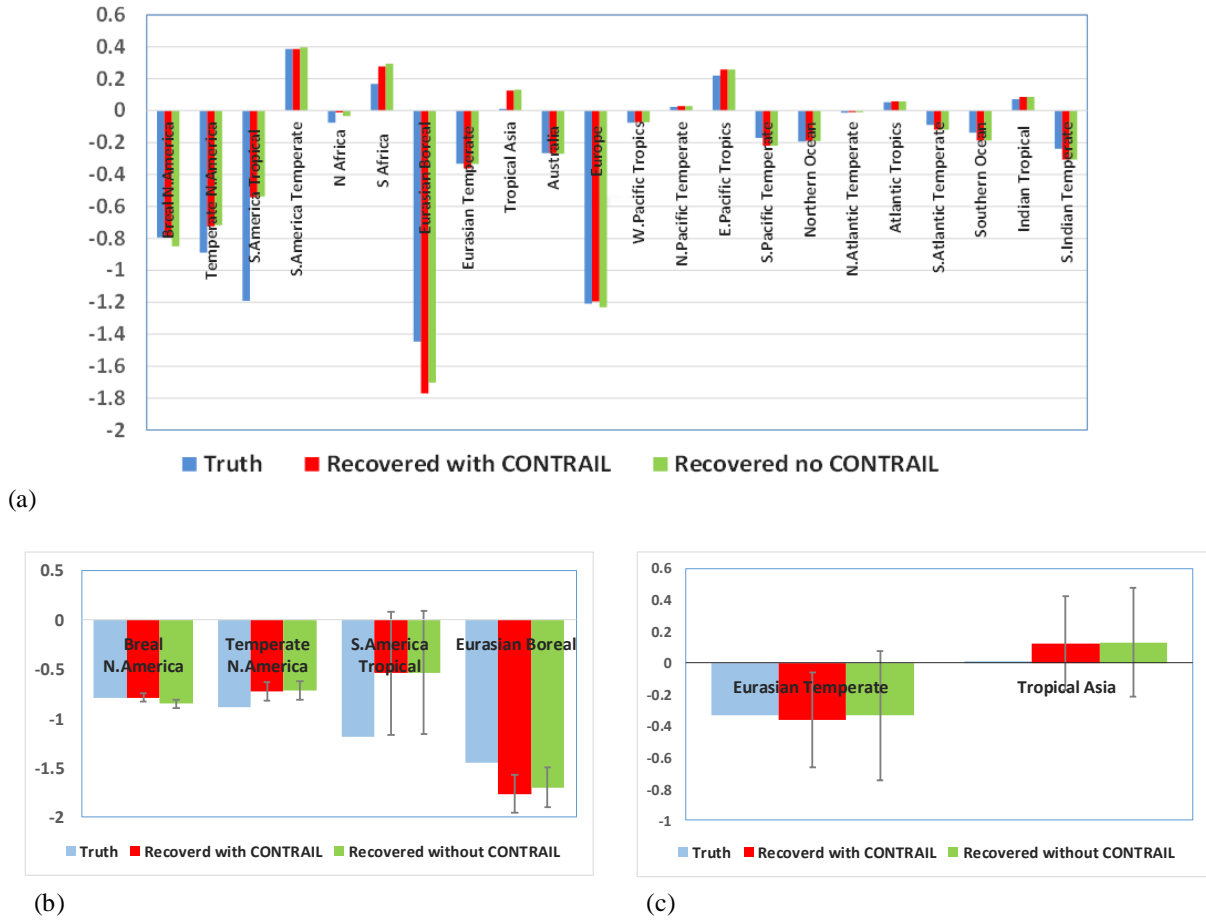
Fig. 7.   Pseudo truth and the recovered mean land fluxes (NEE) with and without CONTRAIL data (a),Pseudo truth and the recovered mean land fluxes (NEE) with relevant standard errors (b) and (c) for the Transcom Regions. Units are in GtC

Conclusions and Discussion

This paper presents a pseudodata experiment carried out to test the performance of the global assimilation system MLEF on estimating carbon fluxes for the Global and South Asian region with CONTRAIL observations in addition to the existing flask and continuous measurements. MLEF method has been tested with a pseudodata experiment for the flask and continuous observations and shown to be performed satisfactorily over the densely observed areas (Lokupitiya et al., 2008). In the inversion scheme of Lokupitiya et al. (2008) two flux components, GPP and respiration were separately considered by adding two biases. However the daytime atmospheric CO_2 observations cannot adequately separate these two components. To separate these components, it requires some additional constraints to the model, for example, ability to assimilate night time

observations and/or other traces such as carbonyl sulfide. Because of these reasons, in this study, flux estimation was done by considering only NEE component without separating it into two components as GPP and respiration.

It is assumed that the observation covariance matrix (R) is diagonal, which means that the observation stations are far enough from each other so that the correlations among their errors are negligible. This was assumed for all flask, continuous and CONTRAIL observations. For the real data experiment, observation error is going to be calculated considering the true observations and the simulated observations by running transport model. In case of CONTRAIL CO_2 concentrations, model-data mismatch is going to be calculated as a representation error that varies with altitudes as used in Verma et al. (2016). The mismatch is very high for measurements that lie closer to the surface while the model performs better for higher altitudes that are not directly affected by the fluxes. Hence the mismatch can be computed by considering the functional dependency of the mismatch with altitude (Verma et al., 2016).

Results of the pseudodata experiment for the land fluxes show better agreement in between the recovered and the true mean annual fluxes. More uncertainty reduction can be observed in Asian region by including the CONTRAIL CO_2 observations. These results reveal that the additional aircraft observations may change the inverted CO_2 flux estimates by imposing further constraints than existing flask and continuous observations.

The observation vector used for this experiment did not include all the CONTRAIL locations for year 2006 as it was not a complete data file for this year. Our assimilation scheme works well with CONTRAIL CO_2 observations. In the future, this model is going to be used with real observations to identify the carbon sinks and sources globally as well as mainly for the South Asian region.

Acknowledgements

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Contextualization and Localization: Acceptability of the Developed Activity Sheets in *Science 5 Integrating Climate Change Adaptation*

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Abstract:

The research aimed to assess the level of acceptability of the developed activity sheets in *Science 5 integrating climate change adaptation of grade 5* science teachers in the District of Pililla school year 2016-2017. In this research, participants were able to recognize and understand the importance of environmental education in improving basic education and integrating them in lessons through localization and contextualization. This study was conducted to develop material to use by Science teachers in Grade 5, which would also serve as a self-learning resource for students. The respondents of the study were the thirteen Grade 5 teachers teaching Science 5 in the District of Pililla. Respondents were selected purposively and identified by the researcher. A descriptive method of research was utilized in the research. The main instrument was a checklist which include items on the objectives, content, tasks, contextualization and localization of the developed activity sheets. The researcher developed a 2-week lesson in *Science 5* for 4th Quarter based on the curriculum guide with integration of climate change adaptation. The findings revealed that majority of respondents are female, 31 years old and above, greater than 10 years above in teaching science and have units in master's degree. With regard to the level of acceptability, the study revealed developed activity sheets in *science 5* is very much acceptable. In view of the findings, lessons in *science 5* must be contextualized and localized to improve to make the curriculum respond, conform, reflect, and be flexible to the needs of the learners, especially the 21st century learners who need to be holistically and skillfully developed. As revealed by the findings, it is more acceptable to have localized and contextualized learning materials for pupils. Policy formulation and re-organization of the lessons and competencies in Science must be reviewed and re-evaluated. Lessons in science must also be integrated with climate change adaptation, since nowadays people are experiencing change in climate due to global warming and other factors. The developed activity sheets strongly support environmental education and will serve as a way to instill environmental literacy among students.

Keywords: Climate Change Adaptation, Contextualization, Localization, Activity Sheets

Introduction

Standards in Science Education today provide expectations for the development of scientific inquiry and environmental stewardship for 21st century learners. Science Education generally concentrates on the teaching of science facts and concepts. It includes work in the science content, pedagogy, processes and strategies. To apply these concepts and facts, Science being taught in the classroom should include experimentation, inquiry-based and real-life experiences of awareness of changes in the environment or climate change. The climate is one of the Earth's life support system. Nowadays, as the earth grows older, number of people increases and continue to demand for water, food, land, transport and energy. Human activities such as the release of greenhouse gases from burning fossil fuels contribute to the current rise in Earth's mean surface temperature. In fact, the activities are not only completely interconnected but also interact with the complex system living on Earth. One of the solutions is public awareness or informing the people by including Environmental Education in teaching science in early grades of schools.

In line with the Republic Act 9152 or "An Act to Promote Environmental Awareness Through Environmental Education" which is also known as known as the *"National Environmental Awareness and Education Act of 2008",* the Department of Education together with other relevant agencies, shall integrate environmental education in its school curricula at all levels, whether public or private, including in barangay daycare, preschool, non-formal, technical vocational, professional level, indigenous learning and out-of-school youth courses or programs. Environmental education shall encompass environmental concepts and principles, environmental laws, the state of international and local environment, local environmental best practices, the threats of environmental degradation and its impact on human well-being, the responsibility of the citizenry to the environment and the value of conservation, protection and rehabilitation of natural resources and the environment in the context of sustainable development.

Recognizing the importance of environmental education in improving basic education and integrating them in lessons would realize these laws. Education sector should take steps to strengthen environmental education in dealing with climate change. Developing and producing teaching materials should be encouraged among teachers since they are the ones who interact and know the needs of learners.Teachers have to intensify lessons regarding environment in all science subjects as well as in classroom discussions, drills and activities that lead in promoting environmental awareness by enhancing environmental education and pursuing activities in schools that nurture the environment and seek to match lectures in the classroom with concrete school-based activities that will preserve and protect the environment.

On the other hand, another underlying issue and concern of teachers teaching in the 5th Grade is lack of teaching guides and learning materials.

Lack of preparedness of the department procuring Grade 5 Learner's Materials (LM) and Teacher's Modules (TG) limit the students and teachers in the access to quality education. The Department of Education must plan adequate procurement and delivery timelines when it comes to learning and teaching materials.

The study was conducted to develop material to use by Science teachers in Grade 5 in the District of Pililla especially for beginning teachers. It would serve as a tool, guide, reference and supplementary material for teachers if found to be accepted, since there are no available materials yet. It could also be a self-learning resource for students.

It could use as a recommending material for the development of learning modules for teachers and students and be used as a guide of other action plans for researchers. It could also help in policy formulation for curriculum development by adapting or integrating climate change awareness to subjects and lessons. The researcher also strongly supports environmental education and believes this to serve as a means to instill environmental literacy among students. Climate change awareness should be a part of the science curriculum because student knowledge of environmental concepts establishes a foundation for their future understandings and actions as citizens of the country.

Methodology

A descriptive method of research was utilized in the research to assess the level of acceptability of the developed activity sheets in fourth quarter *science 5* integrating climate change adaptation of grade 5 science teachers in the District of Pililla during the school year 2016-2017.

A descriptive method research (Shields & Rangarjan, 2013) is used to describe characteristics of a population or phenomenon being studied. It does not answer questions about how/when/why the characteristics occurred. Rather it addresses the "what" question (what are the characteristics of the population or situation being studied?

Participants (Jackson, 2009) answered the questions administered through interviews or questionnaires. The responses were analyzed after the participants answered the questions.

In descriptive research, the study focuses on the present condition. In this study descriptive method research was used, to gather the required data. The questionnaire – checklist was useful in collecting specific data from the teachers, focusing attention on the most important facts to be reported.

The researcher developed a 2-week lesson in *Science 5* for 4th Quarter based on the curriculum guide with the integration climate change adaptation.

The developed lesson material was checked, improved, critiqued and validated by some selected specialists in the field of Science Teaching. After revision, the final hard copies of the developed materials were given to the Science teachers of grade 5 and was checked on the potential use for their teaching.

In data gathering, a questionnaire-checklist was used as an instrument to assess the level of acceptability and it was developed and conceptualized by the researcher. It composed of two parts. The first part determined the personal profile of Grade 5 Science Teachers and second part was composed the level of acceptability of the developed material. In the second part, the respondent answers the questionnaire using Likert Scale. Questionnaire-checklist was also checked and validated. For the validity of the instrument, it was undergone modification through consultation by a panel of specialists in the field of Science instruction and development of learning materials. After validating the checklist, it was given to the respondents to rate the acceptability of the developed lesson materials. The data that were obtained from the questionnaires were summarized, tabulated, presented, analyzed, and interpreted. Possible trends were established which served as the basis for conclusions and recommendations

Data Analysis

The following measures were utilized for the purpose of treating the data:

What is the profile of the teachers in terms of age, gender, no. of years in teaching Science 5, highest educational attainment, number of subjects/loads? ---percentage and rank were used.

What is the level of acceptability of the developed lesson in fourth quarter science 5 integrating climate change adaptation of grade 5 science teachers in the District of Pililla during school year during 2016-2017 in terms of objectives, content, strategies and tasks when grouped according to personal profile? -- weighted mean and rank were used.

Results

Table 1: Composite Table of Level of Acceptability of the Developed Activity Sheets in Fourth Quarter Science 5 Integrating Climate Change Adaptation

Factors	Gender			Age			No. of Years Teaching Science			Highest Educational Attainment			Average		
	Wx	R	VI	Wx	R	VI	Wx	R	VI	Wx	R	VI	Wx	R	VI
Objective	4.12	4	VMA	4.18	4	VMA	4.22	3	VMA	4.20	3	VMA	4.18	2	VMA
Content	4.21	3	VMA	4.26	3	VMA	4.15	4	VMA	4.17	4	VMA	4.20	3	VMA
Task	4.10	5	VMA	4.02	5	VMA	4.08	5	VMA	4.11	4	VMA	4.07	5	VMA
Contextualization	4.50	1	VMA	4.46	1	VMA	4.62	1	VMA	4.53	1	VMA	4.53	1	VMA
Localization	4.35	2	VMA	4.30	2	VMA	4.37	2	VMA	4.45	2	VMA	4.37	2	VMA

Legend

- VMA- Very Much Accepted
- VA – Very Accepted
- A- Accepted
- NMA – Not Much Accepted
- NA- Not Accepted
- VI- Verbal Interpretation
- R-Rank
- Wx- Weighted Mean

The Table 1 presents the composite table of the level of acceptability of the developed activity sheets in fourth quarter *science 5 integrating climate change adaptation* of grade 5 science teachers in the District of Pililla during school year 2016-2017.

The table revealed that in terms of gender, contextualization ranked first with a weighted mean of 4.50 with a verbal interpretation of 'very much accepted'. In terms of age, contextualization ranked first with a weighted mean of 4.46 with a verbal interpretation of 'very much accepted'. In terms of the no. of years in service, contextualization ranks first with a weighted mean of 4.62 with a verbal interpretation of very much accepted. In terms of highest educational attainment, contextualization ranked first with a weighted mean of 4.53 with a verbal interpretation of 'very much accepted'. Overall, contextualization ranked first with a general weighted mean of 4.53 with a verbal interpretation of very much accepted

Conclusions

Based on the results of the study, it could be concluded that majority of respondents are female, 31 years old and above, 10 years above in teaching Science and have a Master's degree. With regard to the level of acceptability, the study revealed that in terms of age, gender, number of years in teaching science 5, and highest educational attainment, with respect to objectives, contents, tasks, contextualization and localization, the developed activity sheets in *Science 5* were very much acceptable.

Based on the findings, the following recommendations can be made

Lesson material in *science 5* must be contextualized and localized to improve to make the curriculum respond, conform, reflect, and be flexible to the needs of the learners, especially the 21st century learners who need to be holistically and skilfully developed. As revealed by the findings, it is more acceptable have to localize and contextualized learning materials for pupils.

Lessons in *science 5* must re-organized since the country experiences weather disturbances and calamities like typhoons and "habagat" (southwest monsoon) during the first quarter of the school year. Lessons about effects of typhoon and precautionary measures are included in the fourth quarter which is the start of the summer season. Policy formulation and re-organization of the lessons and competencies in Science must be reviewed and re-evaluated,

Lessons in science must integrate climate change adaptation since nowadays people are experiencing changes in climate due to global warming and other factors.

Such material will create public awareness and help in reducing the risk of the effects of climate related calamities.

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Institutional Analysis of the Global Climate Change Regime: Literature Review of International Climate Negotiations

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Abstract:

Climate change is the biggest challenge for humanity and international climate negotiations have been put in place to deal with the challenge. However, the international climate negotiations have not been able to achieve the global binding climate agreement to limit the warming under 2 ^{0}C during this century. Previously the literature has covered the impacts, costs, benefits and the efficiency in terms of greenhouse gas emission reduction, sustainable development, climate justice and technology transfer. However less focus has been put on the institutional aspect of international climate negotiations. The aim of the paper is to describe the outcome of the international climate negotiations by institutional analysis and development framework. We conducted a literature review of the international climate negotiations including unilateralism, multilateralism, minilateralism and carbon markets. The results assist to clarify the role of climate governance approaches in tackling climate change.

Keywords: International climate negotiations, institutional analysis and development framework, unilateralism, multilateralism

Introduction

Climate change is the biggest challenge for humanity and to avoid the climate change catastrophe political decisions and technology are needed to put in place. The political decisions can be studied based on rational choice model or system model. Our study is based on institutional model assuming that the institutions have a great impact on which policies are likely to be implemented. The international institutions have formed rules used by countries to organize repetitive activities. The United Nations Framework (UNFCCC) has formed a such set of rules for climate change mitigation and they set the frame for climate action. The UNFCCC was established in 1994 to answer the challenge of climate change framed by the the sovereignty of states as well as common but differentiated responsibilities. At first the objective of the international climate negotiation was to set a binding target for emission reductions, but since that proved to be impossible the outcome of the Paris conference was pledges. The international negotiations have agreed to limit the global warming under 1.5 ^{0}C while the national policies in many countries would lead to warmer climate.

Previously the literature has explained the impacts of climate change and climate mitigation and costs (Rogelj; McCollum; Reisinger; Meinshausen; & Riahi, 2013), (Stern, 2006), sustainable development (Beg, ym., 2002) (Swart;Robinson;& Cohen, 2003) and technology transfer (Abbott, 2009) (Dechezleprêtre; Glachant; Haščič; Johnstone; & Ménière, 2011).

This paper focuses on the institutional characteristics of the international climate negotiations. The aim of the paper is to describe the outcome of the international climate negotiations by institutional analysis and development framework. The institutional analysis and development framework is a systematic method for analysing analysing institutions (Polski & Elinor, 1999) This analysis consists of policy arena, action arena, patterns of interaction and outcomes. The figure 1 presents our simplified model of institutional analysis and

development framework. The policy analysis consists of physical world, the community and the rules. The action arena means the decisions and action put in place. Our analysis includes the most significant strategies of both negotiating and implementing climate change mitigation. Unilateralism, multilateralism, minilateralism, emission trading, carbon taxes and pledges are the most significant aspects of climate governance.
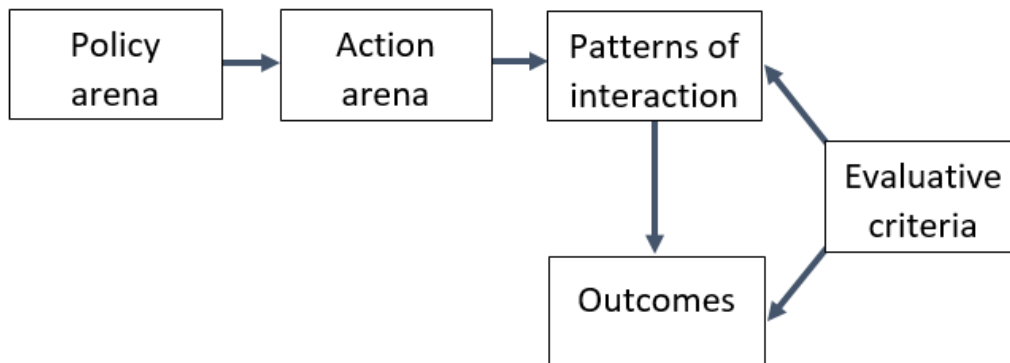
Figure 1. Institional analysis and development framework

Climate change in the international policy arena

Analysis of the international policy arena is part of institutional analysis and development framework. Achieving an ambitious binding global climate agreement is difficult to negotiate because the burden of climate change is not equally divided. Some countries can even benefit from climate change by expanded farmland. The policy arena in climate change is highly fragmented and the resources and funds to implement the necessary actions are mainly channeled through governments with different resources and objectives.

Energy is the most significant part of climate policy. The growth of energy use is also leading to growth of energy goods. Energy policies in a country can impact the climate change mitigation in other countries. As the energy markets gets liberalized the significance of institutions increases. The international policy arena for climate change is shaped by lack of political will for cooperation, lack of binding targets, sovereignty of states and free rider problem. (Deepti, 2012).

Methodology

This is a literature review of the international climate negotiations to conduct an institional analysis and development framework. The available articles were collected from google by using the key words, climate change mitigation, unilateralism, multilateralism, pledges, market based approach and carbon tax because these are the major aspects of climate governance. To limit the number of articles we have only looked at the articles published after 2012.

Results

In total 54 articles were reviewed. A majority of articles focused generally on international climate policy and climate governance. Table 1 presents the articles reviewed.

Table 1   The articles reviewed

Key words	Number of articles	Author
Climate governance Climate policy	14	(Gupta & Mason, 2016) (Bodansky & Rajamani, 2013) (Ventura, et al., 2015) (Stewart, et al., 2013) (Moncel & Asselt, 2012) (Otto, et al., 2014) (Marcucci & Turton, 2013) (Kriegler, et al., 2015) (Riahi, et al., 2015) (Arroyo-Currás, et al., 2015) (Briner & Prag, 2013) (Chaturvedi, 2015) (Glomsrød, et al., 2013) (Gilley & Kinsella, 2015)
Carbon tax	10	(Strand, 2013) (Alton, et al., 2014) (Wang & Li, 2015) (Gale, et al., 2013) (Elliott, et al., 2013) (Elliott & Fullerton, 2013) (Sundar, et al., 2016) (Brooks, 2015) (Pezzey & Jotzo, 2013) (Lamperti, et al., 2015)
Emission trading, trade, carbon markets	10	(Perthuis & Trotignon, 2013) (Uddin & Holtedahl, 2013) (Anon., 2013) (Goulder, 2013) (Lutz, et al., 2013) (Rabe, 2016) (Stiglitz, 2015) (Cormier, 2013) (Erickson, et al., 2014) (Sreekanth, et al., 2014)
Carbon tax and cap-and trade	5	(Goulder, 2013) (Goulder & Schein, 2013) (Lui, 2016) (Sewalk, 2013) (Repetto, 2013)
Minilateralism	8	(Debaere, et al., 2014) (Falkner, 2015) (Hjerpe & Nasiritousi, 2015) (Happaerts & Bruyninckx, 2013) (Nordhaus, 2015) (Potoski, 2015) (Hovi, et al., 2015) (Weischer, et al., 2012)
Minilateralism and multilateralism	3	(Engelbrekt, 2015) (Eckersley, 2012) (Morgera & Kulovesi, 2013)
Unilateralism	2	(Bernauer, et al., 2014) (Schmid, 2013)
Multilateralism, unilateralism, minilateralism	1	(Kulovesi, 2012)

Unilateralism

Unilateral approach to a problem means only that one party makes a promise that is open and available to anyone to join. In other words, anyone can participate the agreement but the specific principles and rules are designed by one party unilaterally. During the Copenhagen conference Kyoto Protocol strengthened the unilateral approach.

This unilateralism has been criticized for contributing to an inequitable distribution of projects. However the unilateral approach has gained some support and raised a question of whether unilateralism could be used more effectively for example even countries that are certainly capable to have more ambitious emission reduction targets but have been rather reluctant to move forward on GHG mitigation unilaterally.

Kulovesi (2012) studied how to address sectoral emissions outside the United Nations Framework Convention on Climate Change (UNFCCC). She assumed that a coordinated international legal response would be the best way to mitigate climate change. The research focused on the aviation and maritime transport that are excluded from the Kyoto protocol. As a conclusion Kulovesi (2012) stated that all possibilities for managing climate change mitigation including unilateral, bilateral and multilateral agreements should be investigated. In addition she argued that the lack of global agreement on how to address emissions has weakened the unilateral approach.

The strongest criticism towards the unilateral regime presented Schmid (2013). He studied the role of unilateralism in unequal distribution of Clean development mechanism. Schmid (2013) claimed that the unilateral CDM does not benefit the least developed countries but only the countries that already have an access to international financing. Schmid (2013) assumed that the purpose of the Clean Development Mechanism (CDM) was to involve the participation of the private sector and engage developing countries in to international climate policy. However according to the CDM rules the purpose of the mechanism is to reduce the greenhouse gas emissions and improve the sustainable development regardless of the participation of the private sector. Schmid (2013) also assumes that equal distribution of the projects is part of sustainable development and therefore the unilateral CDM that does not support the equal distribution of the projects does not improve sustainable development.

A more positive attitude towards unilateralism is presented by Marcucci and Turton (2013) who studied the role of unilateralism technology adoption. Like Kulovesi (2012), Marcussi and Turton (2013) also stated the lack of globally coordinated measures as a major issue in the climate change mitigation. Their study focused on the electricity sector and they concluded that the unilateral regime might lead to some additional technology learning by using a fragmented regime with moderate climate and technology targets.

The studies have moved towards assuming that the unilateral regime has become a default regime and studying the effects of unilateralism instead of comparing it to other models. For example Bernauer (2014) studied whether and how such unilateralism affects public opinion. He assumed that the unilateral policies have naturally been more attractive to politicians as seen from the taxation and trade politics. Bernauer (2014) concluded that cost and sovereignty play a significant role in accepting the unilateral regime. In 2015 Bernauer (2014) studied if the countries can afford to pursue for more ambitious unilateral regime. He stated that the countries aim for balanced or equal international commitments with transparent statement of what is given and what is taken. He concluded that in India and USA the unilateralism is supported and ambitious unilateral climate policies are affordable.

Kriegler et al. (2015) studied the role of unilateralism in establishing the climate targets via the staged accession scenarios. They assumed that the future climate regime involves strong mitigation efforts but does not have sanctions for the parties emitting too much. The authors concluded that the unilateralism can have an extensive role in both establishing or ruing the climate targets. Kriegler et al. (2015) noticed that the focus in climate change mitigation has shifted from global cooperative action to regional climate action. In fact Kriegler et al.

(2015) suspected that the world may be locked into moderate and fragmented climate action because of the institutional, ethical and political challenges. In addition more themes have risen such as the energy security and the development policies and therefore the seek for a universal target might not be the best option.

Multilateralism and minilateralism

Multilateral approach means that more than two parties decide on the solution for a problem and make a promise for anyone to follow. As seen in Paris negotiations the traditional unilateral approach is slowly replaced by the multilateral approach. This new approach includes the multilateral assessment of the progress towards the emission reductions for each country. However, Christina Figueres argued that the multilateral process is an ineffective tool for three reasons. First, climate change is a global problem requiring all the countries to participate in the solution, however the multilateral approach has not been able to fully engage all the parties. Second, every country can make a contribution according to their own capability. This means that the multilateral approach might not support the ambitious emission reduction targets enough. Third a unison rules for all the countries are needed to achieve the global target. However the multilateral approach has not succeeded in establishing unison rules for all the participants.

The multilateralism has regarded having some limitations to answer the global climate change challenge. It might be argued that the multilateral negotiations have not succeeded to reach a universal, binding international agreement to cut emissions. In addition the concerns related to the capability of multilateralism have risen. Therefore alternative options such as minilateralism, standards and climate clubs have been proposed.

It is been discussed whether a multilateral approach should be preferred over a unilateral approach. Even if the unilateralism has become a default model for managing the climate change mitigation it has also been seen as one of the major causes for the failure of the Kyoto mechanism by some researchers. Many researchers proposed alternatives for unilateral model such as multilateral model and minilateralism. Especially the EU has supported the multilateral negotiations leading the kick start of multilateralism at the 2009 Copenhagen climate conference.

Weischer et al. (2012) assumed that the attempts towards multilateral regime have been too slow and the process towards limiting the greenhouse gas emissions has not been adequate, because there are still a gap between the multilaterally formed pledges and the level actual emission reductions needed. Therefore options outside the Kyoto protocol have gained interest and they might assist the Kyoto protocol to reach its target. The so-called climate clubs have been suggested as an alternative for struggling multilateral regime. Weischer et al.(2012) concluded that the climate clubs might be an option for climate change mitigation strategy. Eckersley (2012) presented a critical view on multilateralism. He studied if the multilateralism could be replaced by more flexible model called the minilateralism. He assumed that the strive for multilateralism has not responded the challenge of climate change mitigation. He assumed that the consensus decision making by 194 parties is impossible. However at Durban the international negotiations gained a second chance. He claimed that the minilateralism could be a more convenient option than multilateralism. Like Wong (2015) claimed that the negotiations have not been ambitious enough and the failure to act now will result in need for more ambitious actions in the future. Hovi et al. (2015) also studied the effectiveness of the climate club approach. They assumed that the current development in negotiations is not adequate but the climate clubs could offer an option. They even claimed that even a club with very few members can grow and reduce global emissions effectively. However the study by Hovi et al. (2015) was one of the few studies recognizing the importance of non-climate benefits instead of merely focusing on the greenhouse gas emission reductions.

Harsh criticism towards multilateralism was also presented by Moncel and Asselt (2012). They assumed that multilateralism has not supported a political will to reduce emissions so far. However they stated that the UNFCCC and the Kyoto protocol is no longer solely capable of addressing the problem. They studied how

international institutions outside of the UNFCCC have addressed the climate change and concluded that the climate change is simply too complex issue to be solved through a single multilateral forum. Also Engelbrekt (2015) proposed harsh critique on multilateral approach. He stated that the multilateral negotiations to reach a universal, binding international agreement is not consistent with the scientific knowledge on climate change. He assumes that even theoretically multilateralism is not able to bring long-term stability to institutional form. Instead of multilateralism Engelbrekt (2015) suggests minilateralism as a method to address the problem.

Morgera and Kulovesi (2012) assumed that the slow process towards multilateral regime have raised a question of alternative models. They aimed to find out if standards could be an option for multilateralism. Morgera and Kulovesi (2012) assumed that the whole question of climate change mitigation has become more visible in political debate. For example it was noticed in the Treaty of Lisbon. Morgera and Kulovesi (2012) discussed whether the EU could promote the progress towards multilateralism and more certain emission reductions. However the authors claimed that even if the EU:s multilateral cooperation struggles to fulfill their emission reduction targets it is becoming a default model for managing the climate change mitigation. Minilateral and bilateral cooperation should be used to support the multilateralism. Also Bäckstrand and Elgström (2013) concluded that the multilateral regime is becoming a default model for EU and other models have not been seriously discussed. They assumed that the EU had lost its power in global climate change negotiation after the Copenhagen failure in 2009 because of the unilateralism and unrealistic expectations. Even if the Durban conference in 2011 was more successful for the EU it still has not gained its power back. EU is among the largest greenhouse gas emitters and the weakened power in global climate change negotiations has diminished its options to reduce the emissions.

The most positive attitude towards multilateralism was presented by Stewart (2013). He claims that the multilateral regime is a necessity to address the problem of climate change, because the unilateral and bilateral agreements have failed to do that. He even stated that the multilateral approach to address the climate change can achieve the emissions reductions in addition to build global cooperation.

Wong (2015) claimed that multilateral agreements should be supported by bilateral agreements to achieve the emission reduction targets. She assumed that the negotiations run by the EU have not been able to deliver transformational change needed to limit the emissions. She even claimed that the gap between what we need to do and what we are doing is not closing but widening. Potoski (2015) studied if the voluntary environmental programs, that are also called the green clubs, could be an alternative for multilateral negotiations. He assumed that the government efforts towards ambitious emission cuts have not been adequate and the effectiveness of a multilateral approach towards emission reductions remains unclear. He concluded that the green clubs can play a significant role in addressing the climate change mitigation problem.

As a conclusion multilateral approach has caused criticism because of the weak link to science and failure to answer the real challenge. One researcher even claimed that the multilateralism can nott work even in theory. However plenty of alternative options have been proposed either to support the multilateralism or to replace it entirely. Some researchers have come into conclusion that even if the multilateralism has been criticized it also becoming a default model for EU. One researcher claimed that the multilateral approach is a necessity to address the problem of climate change.

Minilateralism has been seen as a form of multilateralism but with a limited amount of participants. Debaere & al (2014) examine the G20 as a role of minilateralism. They came into conclusion that the EU supports for 'effective minilateralism'. However Falkner (2015) studied the role of minilateralism in the international climate regime. He argued that minilateralism is unlikely to overcome the structural barriers, including national political systems to a comprehensive and ambitious international climate agreement. Hjerpe & Nasiritousi (2015) examined the alternative forums tackling the climate change. They confirm the difficulties in coordinating global climate policy in a highly fragmented governance landscape and the weakness of minilateralism.

Happaerts & Bruyninckx (2013) explored the formation of regime complexes and the appeal of minilateralism. They argue that the minilateralism does not provide a solution for multilateralism, but The G20 does only have a limited, instrumental role in the regime complex. Engelbrekt (2015) also state that the minilateralism cannot wholly replace the legitimizing role of multilateralism.

As a conclusion minilateralism cannot replace multilateralism and fix the structural problems regarding it but can support traditional multilateralism.

Pledges

The Durban platform offered a new strategy for climate change mitigation which was used in Paris negotiations. Instead of aiming for a unilaterally set target each country determined their own targets and roadmaps for climate change mitigation. These pledges cover about 80% of current global emissions and they are part of progress towards multilateralism. The pledges are voluntary created but they go through the official evaluation by the UNFCCC. At first the pledges were supported by some researchers but subsequently the approach has been predicted to fail based on historical and scientific analysis since there is still a large gap between actual pledges and the actual emission reductions required to not to exceed the 2 degrees of warming.

Glomsrød et al. (2013) studied the effect of the pledges on the biggest polluters and he claimed that several factors support the pledges and they are convenient in terms of emission reductions. Briner and Prag (2013) also stated that the pledges could work under certain circumstances even if they have flaws. He argues that the climate change mitigation needs certain flexibility that pledges could provide.

However some researchers think that "the pledge and review" model there is today is not sufficient to mitigate climate change but the global carbon tax would be better. One of the most critical view towards pledges was presented by Riahi et al. (2013). They claim that the pledges would not result in ambitious emission cuts enough, but instead create a "carbon lock–in". This situation would be extremely harmful for the global climate change mitigation. Also Arroyo-Currás et al. (2013) came in to conclusion that the pledges are not ambitious strategy enough for reducing the emissions. Otto et al. (2014) claimed that the pledges are not the best option for climate change mitigation because of the carbon leakage and the lack of efficiency.

Some researcher found that the pledges might be a good option. Chaturvedi (2015) stated that even if the actual pledges do cover the emission reduction needed they are still a good start for fruitful negotiations. However he also stated that Paris will have to find ways to scale up the GHG emission reduction commitments far higher than the current INDC pledges. Hovi et al. (2015) studied the "club approach" as an alternative for a pledge approach. They concluded that the pledges with certain conditions can be a useful part of global climate change mitigation strategy.

Market based approach

A market based mechanism means that emissions are regarded as tradable units with a price. According to the Article 17 of the Kyoto Protocol allows countries to sell their excess emission units to countries that need some. Carbon is traded like any other commodity on a global market also called the "carbon market". The purpose of the carbon market is to reduce the emissions by putting a price for carbon and mitigate the climate change cost-effectively.

One of the most discussed issue is that should emission reductions be based on global carbon tax or could market based mechanism fulfill the targets. By market based mechanisms we mean mechanisms that allows the trading of greenhouse gas emission allowances. The clean development mechanism is the most important market based mechanism.

The researchers have studied the carbon markets from different perspectives. Some researchers have defined market-based policies to include a wide range of tools from carbon tax to tradable carbon allowances. This means basically any mechanism that puts a price for carbon. Lamperti (2015) included taxes and subsidies into the definition of the market based policies.

Carbon markets can be determined either as one of the tools for achieving the emission reductions but also it can be seen as the final aim of the climate change mitigation policy. Ventura & al (2015) defined carbon markets as a tool to mitigate climate change in a cost-effective way. They left out the global carbon tax from the definition. Uddin and Holtedahl (2012) stated the global carbon market as the ultimate aim of the policies. He assumed that the ultimate goal should be the effective market instead of the global carbon tax.

Bodansky and Rajamani (2012) saw market based approach as an opposite to regulated global carbon tax. Nordhaus (2015) also stated that the market based mechanism is the opposite of government lead regulated approach. Many researchers focused to study specific examples of the market based approach. For example Goulder (2013) studied the markets for pollution allowances. Sreekanth et al. (2014), Erickson et al. (2014), Cormier and Bellassen (2012) studied the clean development mechanism as an example of the most significant market based mechanism. Perthuis and Trotignon (2013) studied the EU Emission trading scheme as an example of market based approach. Burtraw (2013), Rabe (2016), Carmton and Stoft (2012), Lutz (2013), Repetto (2013), Anand and Giraud-Carrier (2013) studied only the cap-and-trade markets. They used example from the US, which is the largest emitter with the cap-and trade scheme.

By the start of 2010s it was clear that the market based approach was to be part of global climate change mitigation strategy in the future with CDM as the most significant mechanism under Kyoto protocol. Cramtom (2012) assumed that setting a global price for carbon is essential for emission reductions. He stated that the commonly used cap-and trade system is able to set a price for carbon. Many of the researchers focused merely on the emission reduction. However, Böhm et al. (2012) discussed the possibilities for markets to turn the society more sustainable. They concluded that the carbon markets are unlikely to provide any sustainable benefits because of the capitalist nature of the market.

One of the most positive attitude towards market based mechanism was presented by Goulder (2013). He also assumed that the trading of emission allowances is a desirable outcome of the climate policy and finally he concluded that the cap-and-trade has successfully reduced emissions. Also Repetto (2013) came into conclusion that cap-and trade system is a better way for climate change mitigation than global carbon tax. He stated that unlike the cap-and-trade carbon tax allows emissions to vary according to the economic situation instead of leading to steadily declining emissions.

Perthuis and Trotignon (2013) took a slightly more critical view and stated that carbon market needs flexibility to work effectively. However they highlighted the importance of regulation as well. Uddin and Holtedahl (2013) assumed that the carbon markets have become a preferred mechanism but they discussed the importance of global accreditation and standards in reducing the greenhouse gas emissions. They claimed that the climate change mitigation cannot solely being see as an air pollution problem but in a wider scope.

Similar conclusions were made by Burtraw et al. (2013) who stated that carbon price has been created unilaterally leading in to default markets. They assumed that mechanism to put a price on carbon emissions in the United States has not yet reached its final form and cap-and-trade could be a method for this. They stated that the potential linking of individual cap-and-trade programs could be effective. However, in order to link different cap-and-trade programs the price for carbon should be the same. That is still not the case yet. Leal-Arcas (2013) discussed how to combine the different goals of international trade agreements and climate change regime. He came into the conclusion that the regional trade arrangements could support the ultimate goal of global climate regime if it is designed well. The author claims that the regional agreements are more effective than an attempt to reach global agreement. He claims that the Kyoto Protocol has not succeeded in engaging all

the parties to mitigate climate change with effective results. Newel et al. (2013) concluded in their review that carbon markets could work but they should be improved. He found that the unison global carbon market would be desirable, but also utopist with the current policies. Also Sreekanth et al. (2014) came into the conclusion that even if the CDM does not necessarily contribute the sustainable development it is the most significant tool for climate change mitigation. He claimed that the CDM in spite of its flaws is a necessity for getting closer to reaching the emission reduction target. However Erickson et al. (2014) came into conclusion that the net emission reduction derived from the CDM projects are difficult to assess. Lamperti et al. (2015) stated that market-based policies are not always successful to redirect technical change from the dirty to the green sector like government lead regulation also called the "command and control" policies.

Moarif (2012) studied the market based approach in emerging economies. He found that by implementing both regulatory and market based policy instruments could be beneficial in terms of climate change mitigation and economic growth.

Lutz et al. (2013) presented a more critical view on carbon markets. They claimed that the carbon markets should support the emission reductions in case of the financial recession, but the EU ETS as and cap-and-trade scheme failed to do that. Bodansky and Rajamani (2013) discussed the future climate change mitigation regime and they came in the conclusion that the market based approach is likely to part of any future regime. They found that the climate regime with the market based approach has gained a wide participation. In other words the market based approach is capable of engaging large emitters to the regime. Anand & Giraud-Carrier (2013) presented one of the most critical views on cap and trade. He claimed that there is collusion under cap-and trade and that from the historical point of view the regulation of emissions is inevitable. Nordhaus (2015) concluded that the administrable taxes would be better than markets and less prone to corruption. Unlike Bodansky and Rajamani he claimed that the current regime with market approach has not engaged parties enough to reduce their emissions.

Some researchers came into conclusion that the markets have become a default but slightly ineffective system that should be improved. For example Ventura & al (2015) stated that the CDM has made only a little contribution to sustainable development and emission reductions. They also found that the carbon markets have been facing the financial crises, especially in Europe, which is also the biggest investor. Gupta & Mason (2016) stated that within carbon markets the least developed countries may not be fully empowered to participate the decision making. Also Rabe (2016) stated that cap-and trade model is outdated and a more effective tool for climate change mitigation is needed. He found that in the absence of clear and straightforward federal and international legislation regional climate change policies had risen in U.S He claims that even if discussion on alternative regional tools for climate change mitigation has occurred, the comprehensive cap-and-trade has still remained in core of the climate change discussion.

As a conclusion the market based approach is controversial. Some researchers viewed it as an essential and desirable target for climate change mitigation. Many researchers had more critical view. Market based approach has been as an effective option when the scope of climate change mitigation has been expanded to cover more than just emission reductions.

Carbon tax

A carbon tax means a tax on the carbon content of oil, coal, and gas. Like any other tax the carbon taxes directly raise government revenues. The purpose of a tax is to create public revenues by putting a price on carbon. The carbon tax has been defended by arguing that a tax on carbon would reduce demand for carbon intensive products and thereby reduces total emissions globally. It also creates a stable price for carbon and could possibly work in case when benefits of a certain action are gained in the long term.

Carbon taxes have already been introduced by a number of industrialized countries, including Finland, the Netherlands, Norway, and Sweden. The tax must be well designed to adjust for different market situations. The researchers have tried to focus on how effective the carbon tax is in mitigating the climate change. The studies suggest that an effective carbon tax is high enough to receive an actual response from the emitting sectors such as energy sector. Some researchers regard an effective carbon tax as comprehensive and internationally coordinated. However concerns have raised regarding the motivation of all the large emitters to apply the global tax. Also it has been questioned whether a carbon tax could achieve the emission reductions fast enough. One of the significant issue with carbon tax is that it should be applied globally also in the emerging economies. A carbon tax in the developed nations would lead only to modest emission reductions compared to a global tax.

Carbon tax is one option that has been suggested but some think that it might not be more effective than "the pledge and review". Elliott & al (2012) studied what was the impact of unilateral carbon tax in developing countries. They came into the conclusion that the Border tax agreements, (BTAs) may be effective in reducing the emissions. However the authors found that the carbon leakage resulted from the carbon tax reduces the incentives to mitigate climate change. Other researchers were also positive about implementing a carbon tax. For example Sewalk (2013) stated that the cap-and- trade system is based on weak historical assumptions and the carbon tax would be much better option for the United States. Pezzey & Jotzo (2013) came into similar conclusions but emphasized the importance of planning. They assumed that putting a price on carbon is widely accepted as being far cheaper for countries overall than regulation and tax is the most effective way to put a price on carbon. According to the review by Goulder & Schein (2013) a hybrid scheme with a carbon tax as a part of climate change mitigation strategy is suggested. The authors found that putting a price to carbon is the more cost-effective than direct regulation, but a neither a pure carbon tax or pure cap—and trade can solely solve the problem. They evaluated the effectiveness based on several dimensions such as sharing the political burden.

Elliott & Fullerton (2013) completed another study in US and concluded that the carbon tax might be the best option. Subsequently Elliott & al concluded that carbon tax only in Annexl countries would not be effective but the carbon tax should be adopted globally. Wang & Li (2015) also discussed the importance of carbon tax. They stated that the carbon tax is an effective tool to reduce the greenhouse gas emissions. The authors stated that the carbon tax together with removing fossil fuel subsidies could reduce the greenhouse gas emissions.

Alton & al (2013) completed a study in South Africa and stated that the carbon tax might increase the welfare in the whole country. They assumed that the carbon tax does reduce the greenhouse gas emissions and evaluated the socioeconomic consequences of the carbon tax. Strand (2013) compared the carbon tax to the cap-and-trade system and concluded that the carbon tax is better for importers. He stated that there is not a big difference between the difference between a climate policy involving a carbon tax, and a cap-and-trade scheme under a carbon tax. The question is mainly on should emissions have a cap or not. One of the most supportive comment on carbon tax was presented by Gale & al (2013). They concluded that the carbon tax improves the sustainability in the whole society. They discussed the effects beyond the greenhouse gas emissions. They also stated that the carbon tax could raise significant revenues to cover the costs from the climate change mitigation. Gilley & Kinsella (2015) completed a study in China and concluded that some form of taxes are required on products linked with carbon emissions to reduce the greenhouse gas emissions. They focused on the border tax adjustments and the effects on greenhouse gas emissions.

Sundar & al (2016) stated that the carbon tax is one of the most important tools for reducing the greenhouse gas emissions. They used a mathematical tool to explain the link between the level of the tax and actual emissions. Stiglitz (2015) discussed that the voluntary agreements will fall short and therefore a carbon tax or equal cap-and-trade would be better.

Stiglitz (2015) discussed that a mechanism to put a price on carbon is essential for emission reductions, but fully voluntary agreement is not likely to be able to deliver emission reductions needed. He concluded that the carbon tax would be an effective method to cover the costs of climate change mitigation.

One of the slightly suspicious opinions was presented by Lui (2016). He concluded that the world cap-and-trade scheme would improve welfare better than a world carbon tax. However the political barriers for clean energy investments determine if carbon tax or cap-and-trade scheme would be better in cutting emissions. Lui (2016) was the first to discuss the political barriers related to carbon tax. Also Brooks (2015) was critical about some principles related to the taxation. For example he stated that the polluter pays principle is not functional from justice-based perspective. However generally the critical voices on carbon tax have been very modest.

As a conclusion the effectiveness of the carbon tax has been mainly investigated based on the greenhouse gas emissions. However some studies focused also on socioeconomic effects and welfare. The carbon tax was found to be an effective method to mitigate climate change also when looking at the climate change mitigation from the wider scope beyond the greenhouse gas emissions. However the biggest obstacles were seen a political barriers in many countries. However what is not fully agreed is that should carbon tax completely replace the cap-and-trade or could it be part of the solution.

Discussion

In the mid-90s the discussion on climate change mitigation was very narrow. There was a simple target, measured simply with GHG-emission reductions in the developed Annex 1-countries. Subsequently more themes, measures, sectors and parties have joined the climate change mitigation discussion. These themes include sustainable development, technology transfer and capacity building. At first, targets were presented as reduction in GHG-emissions. Subsequently targets were also presented as technology targets. At first the climate change mitigation was an issue concerning the energy sector in developed countries. However, later on the developing countries also joined the climate change mitigation discussion even if they did not have similar targets as the developed countries. In addition to energy sector, other major emitting sectors such transportation, waste and agriculture have joined the discussion. Traditionally the aim was to reach the climate change mitigation targets by regulation. However this turned out to be politically difficult; so different market based approaches were suggested and implemented. These approaches include trading of emission permits and carbon tax. When the discussion has expanded climate change mitigation has become more challenging to manage for Europeled Kyoto protocol. Therefore a discussion on a new regime and tools has risen.

For the future climate change mitigation regime the targets have been agreed quite clearly. The researchers and the parties have agreed on limiting the warming to 2 celcius degrees globally. However, couple of issues still remain more unclear. First, how much the climate change mitigation should be regulated and how much could be left to markets? Second, what is the optimal amount of participants? Too little participants would make inadequate contribution but too many participants might not agree on the important issues and the decision making would become more challenging. Third, what is the role of carbon tax in future?

The negotiation strategies have led to different outcomes. Unilateral negotiations have led to establishment of emission trading schemes in Europe as well as many other parts of the world. With multilateral negotiations, the outcome was different. There was no universal carbon market but instead pledges and climate clubs. Perhaps in the future, climate clubs become more significant and they can establish their own regulation or carbon markets with carbon tax. Figure 2 presents the options for climate negotiations. Unilatralism has led to limited amount of options while multilateralism has provided more flexibility and options for climate governance.
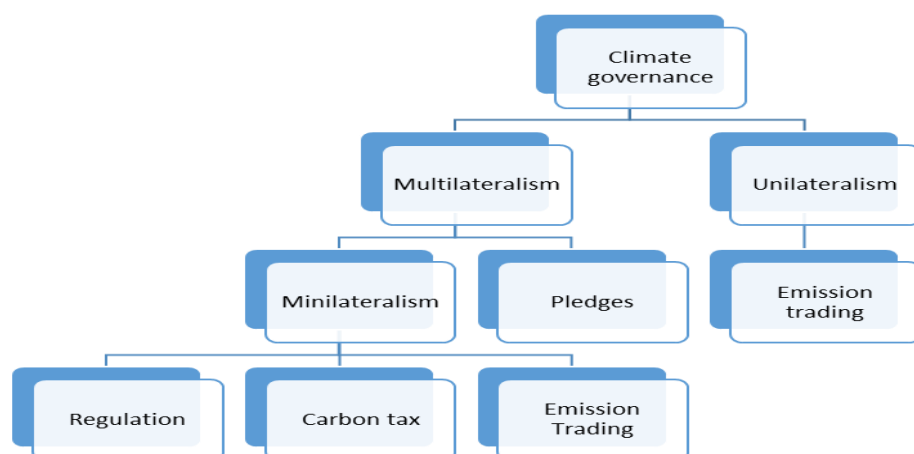
Figure 2. Opions for climate negotioations

Conclusions

The policy arena for the international climate negotiations is shaped by sovereignty of states, diversified interests, and fragmented perspectives on climate change. In addition, emission reductions are not universally well addressed. Achieving the global climate agreement faces some structural barriers as well such as the political cycle in states. This is an obstacle for a long-term binding global climate agreement and it led to EU run unilateral negotiations and establishment of emission trading schemes. The inefficiency of universal negotiations to reduce emissions fast enough and understanding of the global responsibility led to multilateral negotiations and pledges. This approach gave countries more flexibility to act on climate change. However, the multilateral process is slow and does not fix the structural problems behind the global climate agreement.

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Impact of Changed Rainfall Patterns Due to Climate Change and Usage of Available Weather Information by Communities Who Face Human Elephant Conflict (HEC) in Udawalawe, Sri Lanka

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Abstract:

Purpose: Weather information is essential for farmers who face wild elephant conflict because, since their farming activities and elephant encounters both are influenced by the climate conditions. The weather information needs of such communities are different from normal farmers. The purpose of the study was to examine farmers' point of view towards the particular information needs, perception towards existing information sources, perusing climate change impacts and elephant encounters due to climate change etc., in order to focus the attention of policy makers and meteorologists when planning activities for such small communities. This study was carried out in *Panahaduwa* and *Rathabalagama* villages in Udawalawe using a random sample of 50 farmers. Structured questionnaire has been used to collect information. The structured questioner was pre tested with a similar group and local language was used to communicate with respondents. All the respondents were above 18 years old. Both male respondents and female respondents were used to conduct the survey. According to the findings farmers perceive ongoing changes in rainfall pattern in the area. Farmers are more sensitive to changes taken place in local area whereas the level of perception decreases gradually towards countrywide and global climate changes. A majority of farmers has adjusted their crop calendar in response to these changes and perceived that elephant encounters increases in drought periods. Results shown, farmers are aware about the necessity of adaptation of farming practices to face climate change impacts. However, adapting to impacts of climate change while also minimizing the risk of wild elephant damage needs reliable weather information. Even though Farmers use both scientific weather information and traditional knowledge on climate to plan their crop calendar, they rely more on traditional knowledge due to the perceived poor accuracy of weather forecasts. Overall policies and measures are necessary to improve the availability of weather information that facilitates adaptation practices which could reduce damages from elephants as well as extreme weather conditions. Reliable weather information could help their decision making process to achieve a better outcome of production.

Keywords: climate change, perception, weather information

Introduction

Agriculture plays an important role in human lives, providing food and fibre. Farming is an important economic activity in many parts of the world, including both developed and developing nations. (Federico,2005) .The climate is the primary determinant of the agricultural productivity. Weather and climate influence on all components of crop production. (Lizumi and Ramankutty, 2015).Therefore, it needs to understand the future impacts of climate change to support crop production. The agricultural productivity is expected to decrease due to the ongoing climate changes and turbulences. Therefore, many studies have been conducted to address these issues.(Lobell et al., 2008; Dixon et al., 2001; Fischer et al.,2002). The agriculture is affected by many other factors in addition to climate change. One such activity is crop raiding of wild animals. (Hill, 1997) Among them, elephants are concerned as critical where farmers live near to park borders and rural areas. There are a number of studies have been carried out in both Asia and Africa to study the impact of elephant crop raiding and its impact on livelihoods. (Granados and Weladji, 2012.; Naughton-Treves, 1998; Hoare ,2000).Climate change is expected to influence badly on both animals and humans which can make changes in behaviours and feeding habits. (WHO, 2015).Nevertheless, due to climate change, the land productivity is expected to reduce and increase the struggle for land between animal and human.(IFPRI Report, 2009). This will open a new dialogue on elephants' crop raiding behaviour and human elephant conflict.(Thuppiland Coss, 2012.) In the same time, it emphasizes the importance of climate change adaptations to withstand the impacts due to climate change and elephant crop raiding in relevant areas. Due to the competition for land, both humans and elephants are getting damaged all over the world where elephants live (Hoare ,2000). Elephants are critically important not only as a living creature of the environment, but also as a symbol of culture in most of the countries. (Jayewardene ,1994; Wisumperuma, 2004).Therefore, it is important to protect these animals by avoiding possible encounters with human. As a solution for this, climate change adaptation activities should be implemented along with the expected behavioural changes of elephants in such areas. The climate change adaptation of a particular community depends on perusing climatic impacts, loss and damages, socioeconomic characters, policy measures, etc. Adaptation to climate change has the potential to substantially reduce many of the adverse impacts. (Smit and Pilifosova, 2003). The identification of factors affecting to adapt could improve the farmers' adaptability. In this regard, the studies have found out location specific knowledge is important to develop the adaptation. (Gadgil et al.,2002), nevertheless information for various farming decisions could positively help farmers in developing strategies to overcome the perusing risks.(Gadgil et al.,2002)

At this backdrop, the research includes the major objective to analyse the impact of changed rainfall patterns due to climate change and usage of available weather information. This study specifically aims to study the level of sensitivity towards the seriousness of climate change to different geographical areas, awareness of rural farmers on climate change, determine farmers' perception of the causes of climate change; and identify the approaches to climate change adaptation by farmers.

Research Background

The prevalence of human-elephant conflict in some areas of Sri Lanka influences the economic activities and livelihoods in rural communities. It results in crop losses, the deaths of both elephants and human and property damages annually. (Performance Report – 2011 Department of Wildlife Conservation, Sri Lanka;Sathiyapille et al. ,2010; Fernando,2015). The reasons for the human-elephant conflict in Sri Lanka are rapid human population growth, wildlife habitat degradation and deforestation for various purposes.(Fernando et al., 2011) However, an ongoing climate changes have created unfavorable conditions for elephants in the protected forest areas. This has studied in some other Asian countries as well (Thuppil and Coss , 2012.). The unfavourable conditions could create behavioural changes which affect badly on the lives of those farmers who live near the national park borders like Udawalawe National park, Sri Lanka.

In addition to wild elephant damages on the other hand, the farmers in rural areas experience crop losses due to climate changes at the same time. The climate change adaptation practices are not well established and

implemented even though there is an emerging need to use to mitigate the crop loss and damages. The existing adaptations have not used scientific weather information due to a number of reasons like poor credibility and not availability. (National Climate Change Adaptation Strategy for Sri Lanka 2011 to 2016).Weather information usage in Sri Lankan for developing the adaptation is in its initial stage where rural farmers are not sufficiently equipped yet. (National Climate Change Adaptation Strategy for Sri Lanka 2011 to 2016). However, The weather information is essential for rural Sri Lankan farmers in order to plan their crop calendar events and avoid the elephant encounters who are vulnerable to both risks like farmers in Udawalawe, Sri Lanka

Materials and Methods

Research design

To study about the research questions, a survey was conducted in January 2016 in *Panahaduwa* and *Rathamabalagama* area after pre testing the questionnaire with a similar set of respondents. Data collection was carried out by using both structured questionnaire and small group discussions. The respondents were selected randomly. Door to door visit approach was used to collect data. Structured questionnaires were read in local language by the enumerators to the respondents. The questionnaire was inquired about their climate related observations, crop losses, elephant crop raiding behaviour, weather information usage, etc. The crop raiding patterns, crop calendar planning details were collected during the small group discussions in addition to structured questionnaire. The particular two survey tools were used to collect both quantitative and qualitative data. The survey was carried out with 50 respondents. All the respondents were above 18 years old.

Study area

The study area is situated in the border of the Sabaragamuwa province of Sri Lanka. This area is close to the well-known Udawalawe Ath Athru Sewana (Elephant Transit Home) and Udawalwe National Park (6.5159100 latitude and 80.8538800 longitude) Study area is situated near to the electric fences of the Udawalwe National Park border. There are number of researches have been undergone in the Udawalawe National Park area(UNP) and surrounding villages with respect to mitigation of Human Elephant Conflict (HEC). Therefore the study area is not a hidden place for the researchers and it is concerned as one of critical areas where HEC exists in southern Sri Lanka. (Performance Report – 2011 Department of Wildlife Conservation, Sri Lanka 14-17)

In the communities surrounding and adjacent to this UNP Area, high numbers of HEC incidents have been reported. The incidents of crop raiding, injuries, property damages have been reported annually in significant quantities for many years. (Performance Report – 2011 Department of Wildlife Conservation, Sri Lanka 14-17). The area has a poor precipitation. The study area belongs to dry zone of Sri Lanka, which receives less than 2500mm rainfall annually. The area is mostly dry throughout the year (Panabokke and Walgama 1974.). Prolonged drought condition exists for more than three months consecutively after the month of May of every year, with even longer periods in certain years like 2016 when Sri Lanka experienced severe drought conditions all over the island.

More than 300 families live near the UNP border in the studied area and share the park area with wildlife for various purposes such as fuel wood, fodder, building materials, bees' honey ,medicinal plants, etc. The farm lands are situated close to electric fences and in some cases they have cultivated crops up to the electric fence. The study area is poor in infrastructure facilitates like transport, drinking water (both service lines and well water), hospitals, etc. The villagers have no public transport services as elsewhere in the island. They use their own three-wheelers or two wheel tractors for transport their farm products to the market or patients to the nearest government hospital. Transportation during the rainy season is extremely hard due to poor road conditions and flash floods; nevertheless transportation at night is extremely risk due to roaming elephants.

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All populations are Sinhalese Buddhist in the studied area. Their major livelihood activity is farming under rain fed irrigation. Farmers cultivate mainly cassava, low country vegetables like eggplants, chilli as cash crops. Some people grow ground nut as their main cash crop because of drought tolerance, but poor selling price and price discrimination have demotivated such farmers. Paddy cultivation is not practiced and famous among these farmers like elsewhere in the Island due to lack of rains. Agriculture machinery usage is limited to tractors and chemical sprayers. Most of the villagers use family labour and shared labour for their farming activities. Most of the farmers experiences crop losses due to droughts in this area in additions to elephants.

Theory /Calculation

The climate adaptation has been studied for about couple of decades in different parts of the world. Therefore, abundant knowledge has uncovered. But site specific knowledge and relatedness of the research findings are needed to confirm before planning activities for climate change adaptation. Therefore, a structured questionnaire was developed to collect such important information by incorporating findings from different studies to see the level of consistency of them in the studied area. A study carried out in the Nile basin of Ethiopia has identified, that climate adaptation has two- steps, which initially requires farmers' perception that climate is changing prior to responding to changes through adaptation. According to the same study, farmers' perception of climate change is determined by the age of the head of the household, wealth, knowledge of climate change, social capital and agro-ecological settings. The adaptation to climate change has been determined by the level of education of the head of the household, household size, whether the head of the household was male, whether livestock were owned, the use of extension services on crop and livestock production, the availability of credit and the environmental temperature (Deressa et al., 2011.). A similar study in Nigeria also has revealed similar findings as factors affecting adaptation. It has further revealed barriers to adaptation to climate change which include lack of information, lack of money, and inadequate land. (Ofuoku, 2011).There for these, things can be concerned as important factors for adaptation. But in this research, the focus was on the Impact of changed rainfall patterns due to climate change and usage of available weather information by the community for their crop calendar planning. This study would not concern about the factors affecting the adaptation in that particular community because it has concerned in many researchers sufficiently.

Similar Studies have further indicated that the perception or awareness of climate change (Semenza et al., 2008; Sampei and Aoyagi-Usui, 2009; Akterand Bennett, 2009) and taking adaptive measures (Maddison, 2006; Hassan and Nhemachena, 2008) are influenced by different socioeconomic and environmental factors. Some studies have emphasized the importance of famers' perception is important to plan future adaptive plans for them. Their perception about ongoing changes, past experiences and believes on future changes are necessary to guide future adaptation strategies. Studies have indicated that farmers perceive the on-going climate changes and also adapt to reduce the negative impacts of climate change (Thomas et al., 2007; Ishaya and Abaje, 2008; Mertz et al., 2009). Therefore, the research was designed to inquire the particular perception and existing adaptation. The climate information is important to develop the adaptability of farmers. This has concerned in this research by examining the information usage and their trustworthiness. The importance of climate information has been emphasized by a study conducted in Argentina. It has pointed out the value of assessing the climate information for regional agriculture is to gauge user perceptions concerning the use of that information as the initial step. Further, it has revealed the importance of research and outreach to downscaling forecasts temporally and spatially toward user communities would help to narrow down the gap of expectations between user and producer in order to facilitate the trust building process (Letson et al, 2001). A similar study in Sub-Saharan Africa has indicated the importance of knowing the environment in which end users operate and usage information. Purposes of use, Uncertainty, perception was important to determine the dissemination of information for an area. (Vogel and O'Brien, 2006.) The information gap has identified as one of the constraints for climate adaptation similar study Ghana, it has shown barriers included lack of information on adaptation strategies, poverty, and lack of information about weather lead to poor adaptation.

(Fosu-Mensah et al., 2012). The usage of traditional knowledge along with the modern weather forecasting is one of the highly researched areas. The term traditional knowledge is referred to as the place-based knowledge that is rooted in local cultures and generally associated with long-settled communities which have strong ties to their natural environments. Such knowledge is a result of cumulative experience and observation, tested in the context of everyday life, and devolved by oral communication and repetitive engagement rather than through formal instruction. (Ingold, 2003; Sillitoe, 2006, 2007). A study in Uganda has shown the local knowledge system is consisted of four major components :(1)longstanding familiarity with the seasonal patterns of precipitation and temperature, (2) a set of local traditional climate indicators, (3) observation of meteorological events, (4) information about the progress of the seasons elsewhere in the region.(Orlove et al., 2010). Therefore, this study has concerned the similar findings as important to build the adaptation and this research has been conducted to find out similar facts pertain to the local area.

Results and Discussion

Socio-Economic Characteristics of Respondents

Respondents consisted of 24% males and 76% females. However, these females contribute their efforts to farming activities similarly to their husbands. Therefore the collected data do not represented the ideas of anyone who do not have experience in agriculture. The most of males were not found in the houses during the survey time since they were busy with farming activities. The small group discussions were carried out with males in convenient time slots to fill this information gap. Respondents' average age and farming experience are shown in the table 1. This shows that they have fairly good farming experience with respective to their mean age.

Table 1 Respondents average age and farming experience (years)

Variable	Observations	Mean	SD	Min	Max
Respondent's age	50	36.82	14.08	18	64
Farming experience	48	19.19	11.82	1	50

When considering about the occupation of the respondents, they were inquired how they would like to introduce their family occupation. The table 2 shows their typical response to this.

Table .2 Occupation of respondents

Occupation	Frequency	Percentage	Cum.
Full time farming	25	52.08	52.08
Small business	1	2.08	54.17
Part time farming	17	35.42	89.58
Other	5	10.42	100.00

The majority of farm families have fairly small annual incomes. The average annual income was 3,58,096LKR (SD2,70,084). The annual monthly income of the farm families has shown in the table 3.

Table 3 Monthly income of respondents' family

Monthly income	Frequency	Percentage	Cum.
Less than 15,000LKR	37	74.00	74.00
Between 15,000-25,000LKR	10	20.00	94.00
Between 25,000-35,000LKR	3	6.00	100.00

Respondents have farm lands on average 3.071 acres (SD 2.30308).The farm lands are located approximately on average 157.28m (SD249.0045) to the park boundary.

Climate change related information

The respondents had familiarity with the climate changes, 94% of the respondents have heard about climate change and could answer the questions with correct terminology. The table 4 indicates respondents' belief levels about their own familiarity on climate change.

Table 4. Respondents' believe levels about their own familiarity levels on climate change.

Familiarity level	Frequency	Percentage	Cum.
Very Familiar	7	14.00	14.00
Familiar	35	70.00	84.00
Not familiar	8	16.00	100.00

The study identified that farmers perceive ongoing climate changes; .their experience and idea about ongoing climate change were inquired to collect the responses. The results in table 5 indicate that the majority of farmers are experiencing and sensitive to the ongoing changes. However, a tiny portion of respondents expect it in the future.

Table 5 Respondents' experience and belief about climate change

Perception	Frequency	Percentage	Cum.
Currently feeling	42	87.50	87.50
Feel in 5-10 years	6	12.50	100.00

The study revealed that the sensitivity level on the seriousness of climate change and its impacts gradually decrease from their community level to the country level and further decrease towards the world level. This shows farmers are more concerned and sensitive towards the impacts on their area rather than the countrywide issues or world level issues. They believe their community is affected and habitats will be endangered than elsewhere. Table 6 indicates their sensitivity levels on the seriousness of climate change with respect to their community, country and finally the world. The selection percentages of five sensitivity levels differed according to the concerned geographical area.

Table 6 Sensitivity levels on the seriousness of climate change to different geographical areas

Geographical area	Sensitivity level	Frequency	Percentage	Cum.
To Community	Extremely serious	11	22.00	22.00
	Very serious	19	38.00	60.00
	Serious	19	38.00	98.00
	Not very serious	0	0	98.00
	Not at all serious	1	2.00	100.00

To Country wide	Extremely serious	3	6.00	6.00
	Very serious	12	24.00	30.00
	Serious	19	38.00	68.00
	Not very serious	3	6.00	74.00
	Not at all serious	13	26.00	100.00
To world	Extremely serious	2	4.00	4.00
	Very serious	9	18.00	22.00
	Serious	12	24.00	46.00
	Not very serious	11	22.00	68.00
	Not at all serious	16	32.00	100.00

Weather related information is important to farmers in planning their crop calendar and crop management decisions. Traditional weather forecasting is widely used for the crop management decisions. 65.96 % of the respondents use traditional forecast methods and 34.04% of respondents neither use traditional knowledge nor modern scientific knowledge for crop calendar planning. They usually use observations like animal behaviour to forecast about the weather. For forecasting about rain, frog shouting, shouting of eagles, termites moving in search of food, temperature changes, wind speed change, etc. are used. They use observations like sky without clouds, cold nights, and cold temperature in the morning, fog and mist formation, etc. to forecast about drought.

The weather information sources were inquired and it was found that none of them read newspapers. The reason is remote areas have limited access to such material. They need to travel to buy newspapers. Therefore newspaper articles or magazines would not be effective sources for this kind of community awareness about ongoing climate turbulences. Table 7 shows about their weather information sources.

Table 7 weather information sources

Media Source	Frequency	Percentage	Cum.
Television	43	87.76	87.76
Radio	3	6.12	93.88
News paper	0	0	93.88
Television and Radio	3	6.12	100

Also, the perception towards the scientific weather forecasts and usage are poor within the community. The farmers have no credibility towards the information and they use scientific weather information for their day to day activities. But they concern about weather news when it disseminates information on extreme weather conditions like prolonged droughts, floods, etc. It seems that they believe the weather news only when the event is observable and sufficiently large. The severity and scale of the issue have created a demand for scientific weather information. The table 8 shows about the perception of farmers towards the weather forecasts. It indicates that the majority use or believe in them. It has been further attested by their answers for the usage of scientific weather forecasts for crop calendar planning. Only 8.33% of farmers concern weather reports for crop calendar planning. The balance 91.67% use either traditional knowledge or they ignore the weather information for their works.

Table.8 Perception towards the scientific weather reports

Perception	Frequency	Percentage	Cum.
Very accurate and good to follow	6	12.50	12.50
Very accurate but no need to follow	3	6.25	18.75
Neither accurate nor need to follow	28	58.33	77.08
Poorly accurate but no need to follow	11	22.92	100.00

Impacts of changed rainfall patterns and adaptation

92 % of farmers had experienced rainfall pattern changes during the last five years. 59.8% of farmers were aware about climate change adaptations. Among the farmers who were aware about climate change adaptations, 69.57 % of farmers have adjusted their crop cycle according to the rainfall pattern changes. Their most prominent adaptation method was to delay the land preparation until they receive sufficient rains. They have not used short term varieties or drought resistant varieties, etc. This indicates clearly even though they are aware and ready to use adaptation practices, they have not been given the required knowledge. Further, this indicates that they are not receiving accurate weather information in a timely manner. Their common practice is observation of the rains and use different traditional knowledge to forecast about the intensity and duration of rain. Table 9 indicates details about adaptation and experience on rain fall pattern changes.

Table 9 Adaptation and experience on rainfall pattern changes

Event	Sensitivity level	Frequency	Percentage	Cum.
Rain fall pattern change	Experienced	46	92	92
	Not experienced	4	8	100
Aware about climate adaptation	Aware	29	59.18	59.18
	Not aware	20	40.82	100.00
Adjusted Crop cycle according to rain fall (who are aware adaptation)	Adjusted	16	69.57	69.57
	Not adjusted	7	30.43	100.00

Rainfall pattern changes and elephants crop raiding behaviour

Farmers were inquired about their experience related to crop raiding behaviour of elephants. All of them have experienced crop losses due to wild elephant attacks. 82% of respondents have identified special seasons/months where elephant crop raiding is high. 76% of the respondents mentioned drought season as the special season where they experience frequent elephant encounters. 90% of the respondents have expressed crop raiding as the biggest damage in such attacks. This shows that elephants have insufficient feed and water inside the jungle during drought seasons. This reason has impacted on elephants and forced them to change their original feeding habits during droughts. However, the farmers are not well aware about the drought periods and they use local knowledge to forecast the drought. But due to changes in local climate, farmers fail to predict the duration or the beginning of drought by using existing local knowledge any more. Therefore, they cannot cultivate crops which have a less elephant attraction. They usually cultivate the same crop even though they are well aware about elephant attacks. Table 10 shows the details about farmers' experience of crop raiding behaviour.

Table 10 Farmers' experience of crop raiding behaviour

Variable	Response	Frequency	Percentage	Cum.
Have you identified any special season/ months? elephants crop raids are high	Yes	41	82.00	82.00
	No	9	18	100.00
Which season you experienced frequent elephants crop raids	Drought	38	76	76
	No season	12	24	100.00
Which is the damage you experience due to attack during drought	People	1	2.5	2.5
	Crops	36	90	92.5
	Property	2	5	97.5
	Property and crops	1	2.5	100.00

Conclusion

The results of the study indicate that farmers are well aware of climate change and adaptation. Famers are more seriously sensitive towards their community- related climate changes. They perceive ongoing climate changes; however, only 69.57% have taken adaptation measures to reduce its impact of changed rainfall. The study also revealed that adaptation actions are not very familiar and their practice is not technical. The crop raiding pattern of elephants has shown an increase in drought seasons and more crop damages. Elephants face hardships in finding sufficient water and feed during drought periods; Therefore, they come to villages in search of their needs. The farmers experience crop losses due to climate change. However, people still practice the same crop cultivation irrespective of the damages caused by both climate and elephants. The traditional weather information usage is prominent in the community due to the perceived poor accuracy of scientific weather information. Therefore, policies and measures are necessary to improve the availability of weather information that facilitates adaptation practices which could reduce damages from elephants as well as extreme weather conditions. Reliable weather information could help their decision making process to achieve a better outcome of production.

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Drip Irrigation to Enhance Water Productivity of Rice under Climate Change

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Abstract:

Despite the high-water requirement of rice plant, paddy farmers grow rice mainly under flood irrigation. Irrigation in rice plays a major role in improving water productivity. Water productivity is the amount of yield produced per unit amount of water used by crop. Nevertheless, it depends on soil, climate, agronomic practices and method of irrigation. This study evaluates the water productivity of rice grown under the drip irrigation in comparison to flood irrigation. A container experiment was carried out in summer 2015, inside a constructed climate chamber at Dresden University of Technology, Germany. Three large PVC containers were used and in each 18 rice plants were grown (variety Bg300). Three soil matric potential based irrigation treatments were imposed from 14 days after seed establishment until 14 days before physiological maturity. Treatment T1 was maintained with a ponded depth of 3cm water. Treatments T2 and T3 were drip irrigated maintaining soil matric potentials at -150 mbar and -300mbar respectively. Compared to the water productivity of Bg300 under flooded conditions (0.58 kg $/m^3$), all treatments show higher (1.08 kg/m^3, 1.49 kg/m^3 and 1.78 kg/m^3) water productivities. In conclusion, water productivity of rice variety Bg300 shows very good results under drip irrigation in comparison to flood irrigation. Drip irrigation is the most efficient method of water application to crops including rice. However, its acceptance and implementation is relatively low among farmers due to technology involved in design, operation and maintenance. Still, it is a promising technology in rice cultivation in water scarce conditions under climate change.

Keywords: water productivity, Bg300, rice, drip irrigation

Introduction

Rice is the most important staple food in Asia and approximately 90% of world rice is produced and consumed in Asia (Nand Kumar Fageria et al., 2010). Rice production under flooded conditions is highly sustainable. However, rice production needs to increase in coming decades to meet the food demand on growing populations to meet dual challenges of producing enough food and alleviating poverty (Bouman et al., 2007).

Water scarcity in some parts of the world is a limiting factor to produce rice under flooded conditions as explained above. On the other hand, flood irrigation leads to more evaporation, seepage and deep percolation which could be considered as losses under water scarce conditions. Dramatic changes in climate such as drought could severe the environmental conditions unfavourable for Agriculture. On the other hand, land degradation regarding population growth decreases arable land area. This reduces the agricultural production per unit land area or in other words reduces land productivity. Though, rice can grow under a wide range of agro-ecological conditions such as flooded lowlands, temperate cool climates, and drought prone uplands, its yield decline when soil dries below saturation.

Therefore, increasing crop water productivity or the amount of agricultural output produced per unit amount of water used, is a viable solution to overcome the above mentioned challenges.

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Agricultural production including rice cultivation in some countries already practices water saving irrigation practices such as alternate wetting and drying, saturated soil culture, partial root zone irrigation, deficit irrigation, and aerobic rice cultivation.

In all these practices, method of irrigation plays a major role in water savings. For instance, flood irrigation, sprinkler irrigation and drip irrigation can be used in rice cultivation. However, many farmers by convention use flood irrigation as a method of weed control and easy way of practice, but not to save water.

Unlike fertilizers and pesticides, water is not actively traded in Asia and government-administered fees for irrigation water are often low or zero. This discourages farmers from treating water as a scarce resource. On the other hand, they get no incentive on saving water. Therefore farmers in certain areas of China where farmers are charged based on volume of water used for irrigation are practicing water saving irrigation methods. (J.W. Kijne et al., 2003).

Fundamentally different approach to grow rice is aerobic rice cultivation such as production of wheat and maize in non-flooded conditions (Bouman et al., 2002). According to literature, aerobic rice cultivation is practiced large scale in northern China and in Brazil with aerobic rice varieties produced by breeders (Bouman et al., 2002).

Dry seeding is another practice of rice cultivation in dry areas. In this method land preparation is minimum to zero, thereby saves large amount of water. However, these methods are associated with some yield reductions. Therefore, evaluation of water productivity under different irrigation methods is of importance. This could be a motivation for farmers to adopt to these waters saving techniques.

Therefore, objective of this study was to evaluate water productivity of a Sri Lankan lowland rice variety Bg300 under drip irrigation in comparison to flood irrigation.

Drip irrigation is being practiced in many other crops such as vegetable production, fruit production and in horticulture. For instance drip irrigation becomes popular in onion cultivation due to its water application efficiency and precise irrigation management (Shock et al., 2000). Though the method of irrigation is drip, the criteria used to irrigate is based on soil matric potential. This is a very effective technology where plant is irrigated based on the crop water demand. Soil matric potential might be an ideal criterion for irrigation, since variable atmospheric evaporation, soil texture, cultural practices and water management affect rice irrigation water requirements (Kukal et al., 2005).

Materials and Methods

A container experiment was conducted within the laboratory premises of Dresden University of Technology. Duration of the experiment was from 08th of May untill 19th of September, 2015. Soil matric potential based irrigation treatments, namely T1, T2 and T3 were imposed in three large PVC containers as shown in Figure 1.
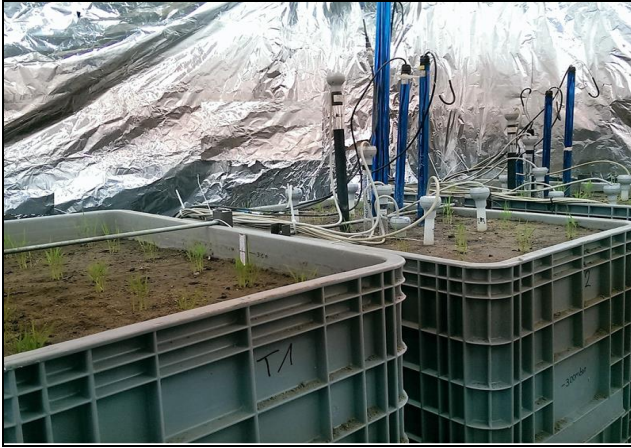
Figure 1: Experimental Set-up in the climate chamber

Treatment T1, was maintained with a 3cm of ponding water level throughout the treatment period (see Figure 2). Other two treatments were maintained at the soil matric potential levels of -150mbar (T2) and -300mbar (T3) respectively throughout the treatment period.

Containers of treatments T2 and T3 were placed on two weighing balances which were connected to a data logger for automatic water balance measurements. However, the container with treatment T1 was placed at the same height with other two, but without a weighing balance.

Figure 2: Irrigation treatment T1 with ponded water.

Construction of climate chamber

Containers were placed inside a constructed climate chamber. It was built using hardboard and steel with a cross sectional area of $4m^2$ and a height of 4m. Climate chamber inner walls and roof were covered with aluminium foils to provide homogeneous lighting conditions. Tropical climate conditions were simulated using growing lamps (Osram power star HQI-BT 400 W/D PRO). Two lamps were hanged 2m above each container. Lamps were connected to a timer to automatically switch on and off creating 12 hours of each day and night cycles.

Installation of soil moisture sensors

Required soil matric potential thresholds in T2 and T3 were maintained using Tensiometers. Bambach digital and T4 tensiometers were installed at 10cm interval up to 40cm depth. Twelve tensiometers were installed in each container at different locations. Control tensiometers were installed at 20cm depth to maintain soil matric potential at threshold level to trigger the irrigation system.

Soil moisture content was measured using time domain reflectometry (Campbell Scientific, TDR100) probes installed at the same depths. Two TDR probes were installed at each depth on each half of the container to check for any variations in the same depth. Both tensiometers and TDR probes were connected separately to two data loggers.

Seed Establishment

Rice variety Bg300 which was developed by Rice Research and Development Institute of Sri Lanka was used in this experiment. Seeds were soaked in water for 24 hours and incubated in a cloth bag for 48 hours. Germinated seeds were Direct seeded in soil at a planting space of 20cm x 15cm in all containers. each container accommodated 18 planting hills. Two weeks after seeding, excess seedlings were removed by leaving 3 plants per planting hill. During these two weeks, all three containers were maintained at saturation to establish similar growth condition at the beginning of the experiment. Two weeks after seeding, irrigation treatments were initiated and continued until two weeks before physiological maturity.

Method of Irrigation

Sub-surface drip irrigation system (Netafim NMC-pro) was installed to irrigate treatments T2 and T3 (see Figure 2). Irrigation system was triggered upon reaching relevant soil matric potential thresholds at 20cm depth.

Each drip emits 1.2 l/hr of water to plants. Single irrigation event was set to 5 minutes and allowed to distribute water for 2 hours. After 2 hours, if required threshold level is not achieved then it re-irrigates to bring down the soil tensions.

Management Practices

After seed establishment, basal fertilizer (N P K) was applied at a rate of 5 kg/ha, 50 kg/ha and 20 kg/ha respectively to all three containers. All other fertilizer applications were carried out according to the local fertilizer recommendations of the Department of Agriculture, Sri Lanka.

When necessary, chemical pest and disease management was carried out. However, throughout the period plants were free from severe pest and disease attacks. Soil in Weed management was carried out manually. All containers were kept at saturation for two weeks to establish homogeneous plant density. At two weeks additional plants were removed by leaving 3 plants per planting hill.

Data Collection

Maximum and minimum air temperatures, soil surface temperature and temperature at weighing balance (to account for changes in resistance in load bearing cells) were measured using temperature sensors. Other climate data such as radiation, relative humidity were measured periodically with a wireless weather station placed inside the climate chamber.

Plant growth parameters such as plant height, number of green, yellow and dead leaves, tillers, panicles, were weekly measured. In addition to that, leaf area index (LAI), leaf nitrogen content (SPAD Value), stomatal conductance, leaf rolling score were measured weekly. Plant phenological developmental stages were recorded

based on BBCH (**B**iologische **B**undesanstalt, Bundessortenamt and **CH**emical industry) codes developed for rice. At physiological maturity, grain yield, total above ground and below ground biomass and root growth were measured.

Soil matric potential and soil moisture contents and irrigation amounts and durations were measured automatically by data loggers.

Results and Discussion

According to the experimental results, highest grain yield was observed in treatment T1. Yield reduction in T1 is non-significant compared to the reference yield under flooded conditions in the field. In comparison to the ponding water depth under flooded field conditions in Sri Lanka, where ponding water depth is usually 5-10cm, water depth can be easily reduced by 2-7cm without significant yield loss. Amount of yield gained in three irrigation treatments were linearly related to the soil moisture stress (Figure 3).
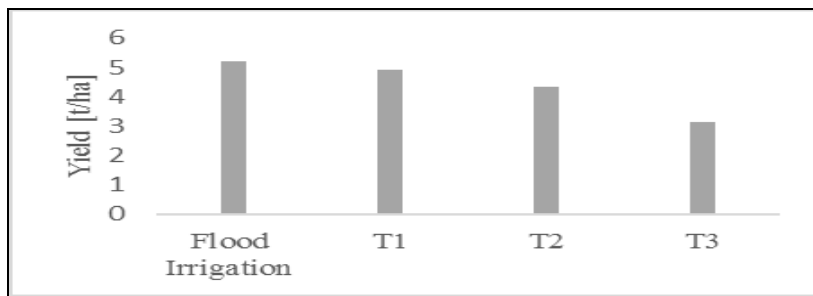

Figure 3: Yield variation in different treatments

Compared to the water productivity of Bg300 under flooded conditions, all treatments show higher water productivities (see Table 1). Highest water productivity and water saving was resulted in most dry treatment T3.

Table 1: Experimental results on water productivity.

Treatment	Water productivity [kg/m3]
T1	1.08
T2	1.49
T3	1.78
Flooded rice (reference)	0.58

Even though highest water saving (83%) and water productivity are achieved in Treatment T3, yield reduction is significant compared to the reference yield. However, comparing yield, water productivity and water savings (72%) of each treatment, best performance is shown in treatment T2.

Conclusions and Recommendations

In conclusion, water productivity of rice variety Bg300 shows very good results under drip irrigation in comparison to flood irrigation. The main advantage of drip irrigation is less water is lost by direct evaporation due to partial soil wetting during irrigation. Drip irrigation is the most efficient method of water application to crops including rice. However, its acceptance and implementation is relatively low among farmers due to technology involved in design, operation and maintenance. Its applicability under soil salinity is to be concerned with the salinity level and leaching requirement. Still, it is a promising technology in rice cultivation in water scarce conditions under climate change.

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Uncertainties and Challenges in Distribution of Groundwater Recharge in Climate Change Scenario

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Abstract:

Groundwater use is of fundamental importance to meet the rapid expanding urban, industrial, and agricultural water requirements throughout the world and also in India. To quantify the distribution of groundwater recharge is a prerequisite for efficient and sustainable groundwater resource management in the arid and semi arid regions. Groundwater recharge in these regions shows variability, as per the assessment carried out by using various methods such as Soil Water Balance (SWB) analysis, Integrated Landscape Hydrology Model (ILHM), Water Table Fluctuations (WTF), Isotopic Tracers methods - Chloride Mass Balance, Carbon-14,etc, WetSpass model, SWAT-MODFLOW model, Empirical method, Numerical Modelling, etc. The interaction of soil, climate, slope, geology, geomorphology, land use land cover, rainfall, drainage pattern and other methods used for recharge determines the recharge process. The study reveals that the reasons causing this variability are ranging from uncertainties in recharge influencing factors to change in climatic conditions. The study also shows that the uncertainties in distribution of groundwater recharge occur differently in different regions, due to the impact of various factors such as change in climatic conditions, land use, soil types, etc. In conclusion, it can be stated that realistic estimation of recharge depends mainly on identifying prominent features influencing recharge for a certain region and probable flow mechanism for targeted aquifer, multiple dependent models / approaches may be applied for estimation of recharge and output may be compared to actual field conditions.

Keywords: groundwater, recharge, uncertainties, challenges

Introduction

Understanding the spatial and temporal distribution of groundwater recharge is a pre-requisite for efficient and effective groundwater management and modelling. In a country like India, it is essential that a careful water balance study is carried out. The scarcity of water and the competition for freshwater demand for domestic, industrial and agricultural uses is increasing. The spatio-temporal attributes of groundwater use data are ideally suited for analysis. It is very common that the period of lowest natural groundwater supplies coincides with largest demand and vice versa. Sometimes region deficient in surface water supplies may be underlain by excessive groundwater reserves. Therefore the need for reliable estimate of groundwater recharge is well recognised. A better understanding of the methods, their applicability and limitations is an important pre-requisite to choose the appropriate techniques for groundwater recharge estimation. Even though the number of studies were conducted, determination or estimation of groundwater recharge still remains fraught with uncertainty.

This paper aims to focus on concepts of groundwater recharge, uncertainties and challenges, which occurs in the study of distribution of recharge, in different regions in accordance with the influence of various prominent factors. Efforts have also been made to adopt the appropriate method for selected region of study suiting the various controlling factors and climate change scenario.

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Groundwater Recharge

Types of Recharge

Recharge is defined as the downward flow of the water reaching the water table forming an addition to the groundwater reservoir (Jacobes J. de Vries & Simmers, 2002). Lerner (1990).

There are three main types:

Direct Recharge: In this type water is added to the groundwater reservoir in excess of soil moisture deficit and evapotranspiration by direct vertical percolation through the vadose zone.

Indirect Recharge: Water from the surface courses like rivers and canals percolate to the groundwater.

Localised Recharge: It is an intermediate form of groundwater recharge resulting from surface of near surface concentration of water.

Recharge Mechanisms

Groundwater recharge involves movement of moisture through the unsaturated zone. There are two major mechanisms, which control such moisture movement viz. Interstitial (Matrix) flow and Macropore recharge. In interstitial flow mechanism recharge, water is stacked as layers one above the other. Any fresh layer of water is added on the surface pushes an equal amount of water beneath so that the moisture of the last layer is added to the   groundwater. During this movement the younger water never overtakes the older water.

Macropore recharge occurs through preferred pathways in the soil matrix like cracks, fractures, solution holes, animal burrows, root tubes, etc. Jacobes J. de Vries & Simmers (2002) suggested an additional term 'preferential flow' to describe flow caused by unstable wetting fronts and differential soil physical characteristics within the soil.

However, not all this water essentially reaches the water table. It might be hampered by low conductivity horizons and disappear as interflow to nearby local depressions, where it runs off or evaporates instead of joining the regional groundwater system. In shallow aquifers   a rise in the water table by recharge could initiate a local groundwater system with associated local seepage discharge within the considered area. A similar problem in areas with a high water table is associated with a time scale: water may initially join the groundwater reservoir but might subsequently be extracted by evapotranspiration.

The term potential recharge as introduced by Rushton (1988) includes the excesses of precipitation over evapotranspiration, which subsequently disappear through a local discharge system or by evapotranspiration from the saturated zone. However, this could become 'permanent' recharge by lowering the water table after extraction. Moreover, lowering of a shallow water table can induce additional recharge by reducing evapotranspiration.

These conceptual problems do occur, normally, in areas with deep water tables, far below the root zone. Under such conditions, virtually all water that passes the root zone is assumed to have escaped evapotranspiration and could recharge the groundwater reservoir.

Various techniques are available for estimation of groundwater recharge (Simmers, 1988; Scanlon, 2002). The recharge estimation methods have been divided into three broad categories (Table 1).

- Methods based on physical parameters
- Chemical and Isotopic methods
- Numerical modelling and Empirical methods

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Methods used in previous studies

Various methods such as Soil Water Balance (SWB) analysis, Integrated Landscape Hydrology Model (ILHM), Water Table Fluctuations (WTF), Isotope Tracers methods - Chloride Mass Balance, Carbon-14, WetSpass model, SWAT-MODFLOW model, Empirical method, Numerical Modelling, etc., of groundwater recharge shows the variability in the climate change scenario.

The present research work summarises the existing studies and their respective significance in various field conditions as well as climate change scenario. These studies are categorised into three broad types based on the analysing methods.

(a) Methods with physical parameters

WetSpass Model

In this WetSpass (Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State) model, the methodology used delivers spatially distributed recharge as a function of vegetation, soil type, slope, groundwater depth, precipitation regime, and other climatic variables. Adnan M. Aish (2010), developed a WetSpass model for estimating spatially distributed, long-term average recharge for the Gaza Strip, for partly semi-arid and partly desert climate, with mostly coastal aquifers. Mustafa Al Kuisi (2013) carried out study for GIS based spatial groundwater recharge estimation in the Jafr basin, Jordan. These investigations have demonstrated that the estimation of groundwater recharge using WetSpass is in good agreement with those obtained by other studies. O. Batelaan (2007) made an attempt to develop spatially distributed water balance model to simulate long-term average recharge depending on land cover, soil texture, topography and hydrometeorological parameters. Parameter estimation for the model is performed on the basis of literature values of water balance fluxes from mainly Belgium and the Netherlands. Moreover, it was concluded that the shallow groundwater levels in valleys cause negative recharge conditions as a result of evapotranspiration by abundant phreatophytic vegetation. GIS analysis showed how recharge strongly varies for different combinations of land cover and soil texture classes. Z. Zomlot et. al. (2015) assessed controlling factors causing spatial distribution of groundwater recharge and base flow in Flanders, Belgium, using spatially distributed water balance model WetSpass.

Soil Water Balance Analysis

Alan Mair (2013) carried out a study to estimate groundwater recharge on the island of Jeju, Korea, for baseline, drought, and climate-land use change scenarios, in which soil water balance analysis was conducted. The Soil Water Balance (SWB) computer code was used to compute groundwater recharge and other water balance components at a daily time step using a 100 m grid cell size for an 18-year baseline scenario.

Gravity Recovery and Climate Experiment (GRACE)

Alexander Y. Sun. (2013) conducted a study aimed for predicting groundwater level changes using GRACE data with an aim to investigate the feasibility of downscaling Gravity Recovery and Climate Experiment (GRACE) satellite data for predicting groundwater level changes and, thus, enhancing current capability for sustainable water resources management. The statistical downscaling method adopted in this study was Artificial Neural Network (ANN).

Integrated Landscape Hydrology Model (ILHM)

David W. Hyndman (2007) prepared a ILH Model which accounts for the processes and mass balance in a most rigorous manner than semi-distributed codes, which tend to lump or oversimplify important watershed processes and use parameters that cannot be independently measured.

Hydrologic model

Mikko I. Jyrkama(2007) conducted a study to characterize both the temporal and spatial effect of climate change on groundwater recharge. In this study, 40 years of actual weather data, and future changes in the hydrologic cycle of the Grand River watershed were used. The impact of climate change is modelled by perturbing the model input parameters using predicted changes in the regions climate.

RIB model

X. Sun (2013) conducted a study for groundwater recharge estimation in arid and semi-arid areas by developing a rainfall infiltration breakthrough (RIB) model, by establishing a relationship between rainfall events and groundwater level fluctuations (WLF) on a monthly basis.

Aquifer systems

Thomas Meixner (2016) carried out a study for analysing the implications of projected climate change for groundwater recharge in the western United States, in which an analysis is presented by synthesizing existing studies and applying current knowledge of recharge processes. In this study, available climate-change projections were analysed to determine likely changes in temperature and precipitation in the sub-regions containing eight representative aquifers. A confidence level (high, medium or low) was assigned to predicted recharge changes. This structured approach provides a template for how large scale regional assessments of the response of groundwater recharge to climate change might be useful for other regions.

SWAT model

Anna Malago et.al.(2016) carried out a case study of the Island of Crete (Greece) for regional scale hydrologic modeling of a karst-dominant geomorphology for quantification of a spatially and temporally explicit hydrologic water balance of karst-dominated geomorphology in order to assess the sustainability of the actual water use, using SWAT model and a karst-flow model (KSWAT model).

WTF, DHB & HB method

T. Ahmadi et. al. (2013) conducted a study for estimation of groundwater recharge using various methods in Neishaboor Plain, Iran, using three methods, based on the water balance principle (rainfall-groundwater level relationship), including Water Table Fluctuation (WTF), Distributed Hydrological Budget (DHB) and Hydrological Budget (HB).

GIS-based NDVI model

Vijai Singhal and Rohit Goyal (2012) carried out a study for understanding effect of rainfall and vegetation density on groundwater recharge using a methodology based on spatial distribution of parameters such as Normalised Difference Vegetation index (NDVI) for part of Pali district in Rajasthan, India. New methodology, for different cause, has been developed and demonstrated for understanding affect of rainfall and vegetation density on recharge.

(b) Chemical and isotopic methods

Tracers Isotope / Carbon-14 and Chlorine Mass Balance composite method

Glenn A. Harrington et. al. (2002) conducted a study, aimed to estimate the average recharge rate over the interval between where the groundwater sample first entered the saturated zone and above. Two environmental tracer methods were applied in this study to the Ti-Tree basin in central Australia to focus on the importance of recharge from flood outs of ephemeral rivers in this arid environment. The results of the two tracer approaches indicate that recharge rates around one of the rivers and an extensive flood plain were generally higher than rates of diffuse recharge that occurred in areas of lower topographic relief. Richard Taylor et. al. (1996) conducted a study for supporting for soil moisture balance approach using stable isotope tracers and flow modelling i.e. it includes three different methods.

Chlorine Mass Balance method

Jozsef Szilagyi et. al. (2011) carried out a study for mapping mean annual groundwater recharge in the Nebraska Sand Hills, USA. Monthly precipitation (P) values came from the PRISM and monthly evapotranspiration (ET) values were derived from linear transformations of the MODIS daytime land-surface temperature values into pixel ET rates with the help of ancillary atmospheric data (air temperature, humidity, and global radiation). The uncertainty level of the resulting recharge-rate estimates can be easily defined from known or estimated levels of inaccuracy in the P and ET variables. Tianming Huang and Zhonghe Pang (2010) conducted a study for estimating groundwater recharge following land-use change using chlorine mass balance of soil profiles in Loess Plateau of China. A model was prepared in this study for the use of chloride to evaluate reduced groundwater recharge following a land-use change. F. Manna et. al. (2016) conducted a study for groundwater assessment in an upland sandstone aquifer of southern California using Chlorine Mass Balance (CMB) method. Felix Oteng Mensah et. al. (2014) conducted a study for evaluation of groundwater recharge estimates in a basin in tropical environment by using natural tracers. The current study evaluates the performance of the CMB methodology in a typical tropical climatic environment where the availability of groundwater resources is critical to socioeconomic conditions of populations and the survival of ecosystems that depend on such groundwater resources for sustenance. Jacob Nyende et. al. (2013) conducted a study in investigating surface water and groundwater in fractured aquifer under influence of climate variability using application of isotopes and recharge analysis in Kyoga basin in Uganda. In this study the impact of climate variability on water resources (surface and ground) was conducted to assess the effect of meteorological forcing on isotopic and recharge characteristics of the granitic and fractured aquifer, using environmental isotopes and also using EARTH model in determining the groundwater levels response to rainfall of the fractured aquifer.

Radiation-based method

Mohammad Valipour (2015) conducted a study aimed to compare radiation-based methods to determine the best method under different weather conditions. The potential evapotranspiration was estimated using 22 radiation-based methods and compared with the Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith method.

(c) Numerical modelling and empirical methods

GROWA model

H. Bogena et. al. (2005) conducted a study for finding out uncertainties in the simulation of groundwater recharge at different scales using GROWA model, which consists of several modules for determining the long-term annual averages of water-balance components, viz. Actual evapotranspiration, total discharge, direct runoff and groundwater recharge.

Frequency Domain Analysis

Joaquin Jimenez-Martinez et. al. (2013) conducted a study for temporal and spatial scaling of hydraulic response to recharge in fractured aquifers, using frequency domain analysis. In order to reduce potential sources of non-linearity coming from unsaturated zone processes, the recharge at the bottom of the soil layer was used as input for the frequency domain analysis. Transfer functions are calculated in a range of temporal scales from 1 day upto a few years, for a fractured crystalline-rock aquifer located in Ploemeur (France), using recharge and groundwater fluctuations as input and output respectively.

Numerical Modelling method

(i) Precipitation model

Sarit Kumar Das and Rajib Maity (2014) carried out a study for finding potential of probabilistic hydrometeorological approach for precipitation-based soil moisture estimation. The time series of in situ soil moisture and meteorological variables at a monthly scale from different monitoring stations across India are utilised.

(ii) Leaf Area Index

P. Ala-aho et.al. (2015) conducted a study for estimation of temporal and spatial variations in groundwater recharge in unconfined sand aquifers using Scots pine inventories. The modelling approach uses data-based estimates for the most important parameters controlling the total amount (canopy cover) and timing (thickness of the unsaturated zone) of groundwater recharge. Scots pine canopy was parameterised to Leaf Area Index (LAI) using forestry inventory data. Uncertainty in the parameters controlling sediment hydraulic properties and evapotranspiration (ET) was carried over from the Monte Carlo runs to the final recharge estimates.

MODFLOW model

Nam Won Kin et. al. (2008) carried a study for development and application of the integrated SWAT-MODFLOW model, with main factors are the land use, surface runoff and other factors. SWAT is a basin scale, continuous time model that operates on a daily time step and designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. MODFLOW is used in layered aquifer systems with the use of modular three-dimensional block-centered finite difference code. The main program of the SWAT-MODFLOW model is simply a modified version of the main program of SWAT. H. Hashemi et. al. (2014) conducted a study with an extended modelling approach to assess climate change impacts on groundwater recharge and adaptation in arid areas. Rainfall-runoff modelling used to simulate runoff from a basin for given meteorological data. Future runoff was simulated using a conceptual box model (Qbox) utilizing the three future climate scenarios for the future periods. A GW flow and recharge model was used to simulate GW flow and estimate aquifer hydraulic parameters by MODFLOW.

WAVES model with improvements

Russell S. Crosbie et. al. (2013) conducted a study for finding out the potential climate change effects on groundwater recharge in the High Plains Aquifer, USA, using WAVES numerical model with improvements. WAVES require three main data sets: climate, soils, and vegetation. The upper boundary condition is forced with climate data and the lower boundary condition is free drainage, consistent with previous studies of the impacts of climate change on recharge.

Empirical Formulae

Oluseyi O. Adeleke et.al. (2015) conducted a study for estimation of groundwater recharges in Nigeria using empirical formulae. In this study comparative analysis of three empirical formulae to estimate recharge, which is a prerequisite for groundwater resource management was carried out.

Results from previous studies

(a) Results based on methods with physical parameters

WetSpass Model

Results of the WetSpass model developed by Adnan M. Aish (2010) show that the estimated distributed recharge can be used in regional steady-state groundwater models and decrease the uncertainty in simulations. Results from the study of Mustafa Al Kuisi (2013), using WetSpass model, shows that there is a good agreement in the simulated recharge. The water balance model of O Batelaan (2007) coupled to a regional groundwater model is applied and successfully tested on the 17 catchments. Study showed that the resulting recharge has a spatial complex pattern, depending to a large extend on the soil texture and land cover. Z. Zomlot (2015) found that the annual recharge shows a large spatial variation and negative recharge occurred in zones with shallow groundwater. Negative recharge occurs, in case the total evapotranspiration is higher than the infiltration. Soil properties appear to have a major contribution in spatial variation of recharge.

Soil Water Balance Analysis

Alan Mair (2013)'s model was capable to estimate recharge in a temperature-humid area of diverse land use, high rainfall temporal and spatial variability, high topographic relief and generally high infiltration capacity. The model produces reliable estimates of spatially-varying recharge in temperature-humid climates.

GRACE Model

It was observed in the study, conducted by Alexander Y. Sun. (2013) that, downscaling of GRACE data to multiple wells at the sub-grid scale is feasible. Practical application of model for local water resources is limited. Approach developed can be applied to force multiple ANNs developed for a network of wells, the outputs of which can be combined via spatial interpolation techniques.

ILHM

ILH Model accounts for the processes and mass balance in a most rigorous manner than semi-distributed codes, which tend to lump or oversimplify important watershed processes and use parameters that cannot be independently measured.

Hydrologic model

The results of the study indicate that the overall rate of groundwater recharge is predicted to increase as a result of climate change. It is also observed that the higher intensity and frequency of precipitation could also contribute significantly to surface runoff, while global warming may result in increased evapotranspiration rates.

RIB model

The Pearson correlation coefficients indicate that the results of the rib model are more significantly correlated to observed values than those of the CRD method. The Spearman correlation coefficients between rainfall and

observed WLF together with recharge estimates obtained from other methods in these areas demonstrate that the recharge estimates on a monthly basis are more realistic than those on a daily basis.

Aquifer systems

In the most of the systems studied, vadose zone storage and the dynamic interaction of surface water flows with groundwater recharge was not included. Recharge to the Death Valley regional flow system occurs almost entirely from infiltration of precipitation and runoff in mountain systems and is low, reflecting the area's extreme aridity. Recharge to the Central Valley is dominated by irrigation recharge, with mountain system recharge (MSR) and diffuse recharge playing subsidiary roles. Diffuse recharge is the primary recharge mechanism for the Columbia Plateau aquifer system, with irrigation providing the balance of the recharge. Recharge to the Williston Basin consists almost entirely of diffuse recharge, with a small amount of focused recharge through streambeds.

SWAT model

Results demonstrated that the karst-flow model correctly simulated the discharge of springs increasing the SWAT model performance. However, the karst-flow model markedly overestimated the discharge for five springs, may be due to the quality of the observed data.

WTF, DHB & HB method

Hydrological Budget (HB) was used to calculate groundwater recharge, which shows 61 % of the total groundwater recharge including net groundwater inflow, infiltration and irrigation return flow. The difference between groundwater recharge rate estimated through Distributed Hydrological Budget (DHB) and Water Table Fluctuation (WTF) is less than 20 %.

GIS-based NDVI model

With the increase in value of NDVI from 0.13 to about 0.18, the value of groundwater recharge increases, as water is retained at the surface due to increase in vegetation density and thus has stronger chance of infiltrating into the ground. However, when value of NDVI is beyond 0.18, groundwater recharge starts decreasing with increase in NDVI value.

(b) Results based on chemical and isotopic methods

Tracers Isotope / Carbon-14 and Chlorine Mass Balance composite method

Glenn A. Harrington et. al. (2002) recorded the results that the mean carbon-14-derived recharge rate for the entire Ti-Tree basin is 3.5 mm/year. However, the median carbon -14-derived rate is only -0.9 mm/year, which is close to the mean rate determined from chloride mass balance (0.8 mm/year). Recharge rates are generally higher for boreholes located around the Allungra Creek floodplain and the northern section of the Woodforde River, compared with other parts of the basin. This is consistent with enhanced recharge in these areas after infrequent storm events. Richard Taylor et. al. (1996) noted in soil moisture balance technique that despite the slight rise in the annual rainfall observed between the periods, the increase in recharge results primarily from changes in land use, which have reduced evapotranspiration. Results simulation of groundwater flow model show that the water table in the regolith can be adequately represented when recharge is applied at a rate of 200 mm per year. Stable isotope measurements of Entebbe precipitation, supported in part by the limited data set generated in the study area, reveal that heavy monsoonal rainfall in the Victoria Nile basin not only is more depleted in heavy isotopes than lighter rains in a manner commonly known as the 'amount effect' but also

displays an isotopic composition which, falling parallel to the global meteoric waterline, is unaffected by evaporation.

Chlorine Mass Balance method

Jozsef Szilagyi et. al. (2011) found that the mean annual recharge rate estimates based on this method were consistent with independent estimates based on base flow/ stream flow, groundwater modelling and chloride mass balance given their uncertainty ranges. The semi-arid climate of a large portion of Nebraska Sand Hills region necessarily increases the error range for water balance recharge estimation. Tianming Huang and Zhonghe Pang (2010) found the results that the regional afforestation and other land-use conversions have resulted in deep soil desiccation and have caused an upper boundary to form with low matrix potential, thus preventing the soil moisture from actually recharging the aquifer. F. Manna et. al (2016) observed that the annual total volume of runoff discharged at the outfalls varies. The aerial distribution of chlorine demonstrates the absence of a visible trend, with a uniform distribution of values across the site and observation wells shows no evident trend, indicating no source of chloride other than atmospheric. Felix Oteng Mensah et. al. (2014) noted the results that the observed pattern is consistent with conditions of lower relative humidity than 100 % and high ambient temperatures as is common in the study area. The ratio of the rarer isotope to the more abundant isotope provides an indication of the relative enrichment of the two isotopes in the medium or the original source of recharge. Jacob Nyende et. al. (2013) found the result showing that oxygen-18 and deuterium compositions mostly plot below the Local Meteoric Water Line (LMWL) indicating that the surface water and groundwater in the aquifer was exposed to evaporation before or in the recharging process and groundwater levels response to rainfall events by the EARTH method is the quantitative estimation of groundwater recharge for Pallisa District watershed,

Radiation-based method

The results indicate that each method estimates the potential evapotranspiration under specific weather conditions. The results show that the Stephens method estimates the potential evapotranspiration better than other methods for provinces of Iran.

(c) Results based on numerical modelling and empirical methods

GROWA model

H. Bogena et. al. (2005) found the results of the groundwater recharge calculation for the macro scale study area and the corresponding uncertainties as a result of the uncertainties of all data sets used. In the consolidated rock region, the low hydraulic conductivity of the solid rocks leads to groundwater recharge rates that are often less than 100 mm/a. Only the karstified carbonate rocks show significantly higher hydraulic conductivities and the groundwater recharge rate increases to more than 300 mm/a. In the unconsolidated rock region, groundwater recharge levels between 200 and 300 mm/a are most common. This distinct dichotomy in the distribution of groundwater recharge rates is also apparent for the corresponding uncertainties.

Frequency Domain Analysis

The computed transfer functions are plotted for the wells located around the pumping site, showing the general pattern, i.e. a flat section at low frequency, a decreasing section at intermediate frequency, and finally, different behaviours at high frequency are observed in all cases, which confirm that the fractured aquifer acts as a low-pass filter. No remarkable changes are detected for the characteristic response time, or in the asymptotic behaviour at low frequency.

Numerical Modelling method

(i) Precipitation model

Precipitation-based probabilistic estimation of soil moisture using the proposed hydrometeorological approach is tested with in situ observed soil moisture data and with soil moisture data of the Climate Change Initiative project. The results are found to be promising and able to provide the information on uncertainty associated with the estimation. Result also shows that the parameter of the developed model is linked to the predominant soil textural class.

(ii) Leaf Area Index

The WTF method agreed well with the simulated values, with overlapping estimates between the methods for all but two recharge events. Also the median value of simulations was close to the WTF method, with some bias to higher estimates from the simulations. Both annual recharge and infiltration displayed an increasing trend.

MODFLOW model

Nam Won Kin et. al. (2008) observed that the results, which were compared and simulated hydrograph by SWAT was compared with that by SWAT-MODFLOW, shows that the SAWT was notable to correctly reproduce the stream flow dynamics in low flow, even after a comprehensive calibration. The differences in the low flows were due to insufficient baseflow resulting from the limitation of the groundwater module in SWAT. H. Hashemi et. al. (2014) found the results that, in arid regions, the change in precipitation, surface runoff, and GW recharge are expected to be the most substantial consequence of climate change. In the future scenarios, there will be no significant change for all climate variables during the spring and summer season relative to the historical climate. During the cold and wet seasons, both temperature and potential evaporation is slightly increased in all projected scenarios. In general, the average reduction in precipitation in the near and far future is about 2 and less than 1 % respectively.

WAVES model with improvements

The trend show expected relationships between recharge and rainfall (positive correlation), soil texture (higher rates under coarser-textured soils), and vegetation (lower recharge rates under perennial vegetation). The historical climate baseline raster produces spatial trends that are consistent with previously published recharge estimates for the High Plains.

Empirical Formulae

The result revealed that the three empirical formulae gave comparable results. Low rainfall causes low groundwater recharge infiltrating into the aquifer, this is due to increase in temperature and evapotranspiration and vice versa. Low recharge causes high runoff over the surface. It is evident that the recharge in no-stationary and likewise, the annual rainfall, but are stationary after the second differencing, hence there exists a long relationship between the climate parameters.

Analysis/ Discussion on previous individual studies

(a) Methods with physical parameters

The WetSpass model was used in various regions such as Gaza strip, which is a characteristically semi-arid and desert climate, in Jafr basin, which is arid desert and in Belgium and the Netherlands, where area is dominated by agriculture, forests, built up areas and meadows. GIS-based WetSpass methodology is a tool which can simulate the spatial distribution of long-term average groundwater recharge.

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Soil Water Balance Analysis

The Soil water balance model does not include a mechanism to account for additional sources of groundwater recharge, such as fog drip, irrigation, and artificial recharge, and may also overestimate evapotranspiration losses. As such this study represents a conservative estimate of total recharge.

GRACE Model

Results indicate that GRACE data play a modest but significant role in the performance of Artificial Neutral Network ensembles, especially when the cyclic pattern of groundwater hydrograph is disrupted by extreme climate events.

ILHM

ILHM is well suited for forecasting purposes because it allows forcing data and component process models to be interchangeable.

Hydrologic model

Groundwater recharge is influenced not only by hydrologic processes, but also by the physical characteristics of the land surface and soil surface. While knowing the average change in recharge and groundwater levels over time is important, these changes will not occur equally over a regional catchment or watershed. Studies concerned with climate change should therefore also consider the spatial change in groundwater recharge rates.

RIB model

The RIB model is capable of recharge estimation, if specific yield is known and certain assumptions are met. RIB model can be used only under certain conditions in shallow unconfined aquifers with relatively low transmissivity.

Aquifer systems

Together these results show that the wet areas will get wetter and the dry areas will get drier. Recharge is a threshold process, as dry places get drier, recharge will decrease more sharply than precipitation declines. The results of available studies indicate that this overdraft will become more severe as recharge declines and pressure to increase groundwater pumping grows. In contrast, there is a potential for increased recharge across the northern set of aquifers, though confidence in the expected changes is low

SWAT model

SWAT model has allowed the estimation of the water balance of Crete resulting in significantly different estimates. In the wettest year the main component of hydrological process was the deep aquifer recharge, while in the driest year the evapotranspiration had the main role. As a consequence, during the wet conditions there was high infiltration, but also the surface runoff was larger than that during driest and normal hydrological condition.

WTF, DHB & HB method

Hydrological Budget (HB) is a lumped method and wouldn't report any further information about distribution of groundwater recharge rate in region. Groundwater recharge resulting from both rainfall deep percolation and irrigation return flow for each sub-zone can be estimated using DHB method. WTF method gives distinct results for contribution of rainfall and irrigation return flow towards groundwater recharge. There is a good agreement

between groundwater echarge estimated using the DHB and WTF model. The difference between these results and those of the HB method arises from (1) considering net groundwater inflow as an average groundwater recharge in this method and (2) assuming constant groundwater level to calculate groundwater flow from one cell to adjacent cell during a month time period which is not well matched with aquifer condition in reality,

GIS-based NDVI model

It can be seen that overall there is a linear trend between groundwater recharge and rainfall. The value of groundwater recharge depends strongly upon the density of vegetation before the monsoon. Increase or decrease in groundwater recharge would be due to the reason that vegetation density increased to such a level that the interception and absorption of water out weights the factors responsible for further increase in recharge.

(b) Chemical and isotopic methods

Tracers Isotope / Carbon-14 and Chlorine Mass Balance composite method

Glenn A. Harrington et. al. (2002) discussed that the stable isotopic compositions and, to a lesser degree, the raw chloride concentrations of soil and groundwater samples provide compelling evidence that the groundwater in the Ti-Tree Basin is recharged only after the most intense rainfall events of at least 150 to 200 mm/month. Carbon-14 data was combined with physical parameters including sample depth, aquifer depth, and distance from the groundwater flow divide to obtain estimates of the average recharge rate between where a groundwater sample first entered the saturated zone and the borehole. This approach, however, is limited by both the ability to construct accurate groundwater flow lines and having a sample (bore) density that reflects the scale of the different recharge areas. Richard Taylor et. al. (1996) shown that owing to the conservative behaviour of stable isotopes in low-temperature groundwater systems, groundwater will retain the isotopic signature of recharging precipitation provided that (1) the isotopic content of the incident rainfall is not affected by soil zone processes immediately before infiltration, and (2) the source of recharge is restricted to the direct infiltration of rainfall.

Chlorine Mass Balance method

Jozsef Szilagyi et. al. (2011) discussed that the associated error bounds in the recharge estimates may be significant in arid and semi-arid regions where a large portion of the precipitation was evaporated/ transpirated. Such uncertainty was considered acceptable for many problems in view of the current state of uncertainty associated with other recharge estimation techniques. Tianming Huang and Zhonghe Pang (2010) in their study shows that the decrease in groundwater recharge when the vegetation is converted to a type with higher water demands. In the study by F. Manna et. al. (2016) the main uncertainty in the application of the method is related to the assumption that atmospheric chloride must be the only source of chloride in the sub-surface system. Uncertainties can be derived by the slope effect, i.e. the mixing of water due to up-slope recharge. This process is believed to minimally affect the results of the analysis because of the topographic and hydrogeological characteristics of the study area. Felix Oteng Mensah et. al. (2014) mentioned that the ratio of the rarer isotope to the more abundant isotope provides an indication of the relative enrichment of the two isotopes in the medium or the original source of recharge. The sources and origin of groundwater recharge in the Voltaian was assessed using stable isotope data of precipitation, groundwater, and surface water from parts of Voltaian. Jacob Nyende et. al. (2013) mentioned that the clustering of groundwater samples observed suggests that both evaporation and isotopic exchange with the aquifer minerals may be occurring into the system. The effect of evaporation is greatest for light precipitation.

Radiation-based method

Evapotranspiration has a significant role in irrigation scheduling and water resources management. The highest precision of evapotranspiration could be obtained using lynsimeter or imaging techniques, but their costs are too

high. The radiation-based method is one of the most widely used methods to estimate potential evapotranspiration. Finally, a list of the best performances of each method is presented to use in other region studies according to mean, maximum, and minimum temperature, relative humidity, solar radiation, elevation, sunshine, and wind speed. The precision of estimation by radiation-based methods was very sensitive to variations of the parameters used in each method. Thus, the coefficients of the radiation-based methods need to be adjusted based on weather conditions of each province.

(c) Numerical modelling and empirical methods

GROWA model

Most parts of the consolidated rock region show uncertainties well below 20%, except for the karstified carbonate rocks with significantly higher values (more than 30%). The unconsolidated rock region, on the other hand, shows uncertainties between 15 and 40%. In order to facilitate an analysis of the differently scaled data ensembles on the calculated groundwater recharge, averaged values of the uncertainties in percent of the mean groundwater recharge are calculated. The differences between the scales cannot be generalised since the identified uncertainties are determined by the individual characteristics of the catchment area and the available database.

Frequency Domain Analysis

The estimation of recharge at the bottom of the soil horizon is uncertain. The observed non-classical log-log slopes for some observation wells are not influenced by uncertainties in the computation of input recharge, and thus correspond to an intrinsic property of the aquifer.

Numerical Modelling method

(i) Precipitation model

Soil moisture has a significant impact on the temperature-evaporation-precipitation feedback loop and plays a significant role in numerical weather prediction using climate variables at a regional scale. It also controls the terrestrial water balance through partitioning precipitation among infiltration, runoff, and evapotranspiration. The capillary action that determines the evaporative demand and withdrawal of the water through plant roots is driven by soil moisture content.

(ii) Leaf Area Index

The method used here to estimate LAI from forestry inventories introduces a new approach for incorporating large spatial coverage of detailed conifer canopy data into groundwater recharge estimations.

MODFLOW model

SWAT is not able to represent the spatial distribution of the groundwater table because the model is an HRU-based quasi-distributed model rather than a grid-based fully distributed model. Since SWAT-MODFLOW uses MODFLOW as the groundwater model, it is capable of calculating the spatially distributed groundwater table and also capable of simulating the spatio-temporal variation of groundwater recharge rates. H. Hashemi et. al. (2014) observed that the results of projected climate variables (precipitation, temperature, and evapotranspiration) show no significant increase or decrease in rainfall quantity relative to the historical climate but a slight increase in surface runoff.

WAVES model with improvements

The trend for future recharge projections differs from the trend of the future rainfall projections. There is a general trend across all three sites for the slope of the mean annual rainfall versus mean annual recharge to decrease with increasing recharge. Model results show a trend with projected increases in recharge for the low global warming scenario and then a reduction in recharge with further increases in global warming that is not related to changes in rainfall.

Empirical Formulae

There is no significance at any level among the other parameters with regression analysis, which was conducted to evaluate the effect of climate parameters on estimated recharge. All parameters showed minimal relationships to estimated recharge, except precipitation, which showed a dominant role of rainfall percolation of water into the ground in the study area.

Summary/ Conclusions from previous individual studies

(a) Methods with physical parameters

WetSpass Model

Adnan M. Aish (2010) concluded that the comparison of results of WetSpass model and previous studies shows good agreement and indicates the validity of the simulated recharge, changes in land use impact the recharge and the presented recharge map can serve not only as a basis for future land use conditions, but also as a basis for comparisons with past land use conditions, and the model is especially suitable for studying effects of land-use changes on the water regime in a basin. Mustafa Al Kuisi (2013) concluded that the aquifers receive recharge from the western highlands by direct and indirect infiltration of rainfall. This model is specially suited for studying long-term effects of land use changes on the water regime in a watershed. Z. Zomlot (2015) concluded that the groundwater is strongly influenced by soil texture and land use; the spatial correlation, however, is relatively low

Soil Water Balance Analysis

Soil water balance Model can produce reliable estimates of spatially-varying recharge in temperature-humid climates.

GRACE Model

GRACE satellite data only takes ΔTWS but not changes of individual hydrologic components such as surface water, soil moisture and groundwater.

ILHM

ILHM is well-suited for forecasting purposes because it allows forcing data and component process models to be interchangeable; thus a model developed and calibrated with current data can be rapidly converted to a forecast simulation by adding the appropriate component process code.

Hydrologic model

Groundwater resources are related to climate change indirectly through the process of recharge, and directly through the interaction with surface water bodies such as rivers and lakes. The process of groundwater recharge is not only influenced by the spatial and temporal variability in the major climate variables, but also dependent

on the spatial distribution of land-surface properties and the depth and hydraulic properties of the underlying soils.

RIB model

The sensitivity analysis showed that the recharge rate by the RIB model is specifically sensitive to the parameter of specific yield; therefore the accurate representative specific yield of the aquifer needs to be selected with caution. The RIB model is a simple and efficient method to estimate groundwater recharge and fill water level data gaps in shallow unconfined aquifers where groundwater levels respond distinctly to rainfall.

Aquifer systems

Anticipated changes in recharge mechanisms display definite regional patterns in magnitude and confidence. MSR is expected to decrease with high certainty in the southern and western portions of the region and with lower certainty in the northern and eastern portions. Patterns of expected recharge change (in total recharge and recharge mechanism) inherit all of the uncertainties of the underlying GCMs and downscaled average climatologies. Uncertainties regarding the impacts of future climate change on MSR, focused recharge, and irrigation recharge present the greatest opportunities for improvement through process level studies.

SWAT model

The seasonal variation of volume of springs suggests that these valuable sources should be conserved and preserved in particular from April to September when available volumes are the lowest and agriculture and tourism demand increases. The analysis of the water balance also showed that water resources are not homogeneously distributed in Crete and change significantly in different hydrological conditions.

WTF, DHB & HB method

In the HB method specific yield is the only estimated parameter. Although it plays a critical role in the water budget, this parameter has a limited domain of variation. Accuracy and reliability of groundwater recharge estimated with these methods depends on those of the input datasets and their assumptions. The DHB and WTF models provided spatial and temporal distribution of natural groundwater recharge. The WTF model clearly exhibited groundwater recharge components.

GIS-based NDVI model

This delivers a new methodology for understanding affect of rainfall and vegetation density on groundwater recharge based on spatial distribution of these parameters in a given geographical area. The study establishes a very strong polynomial correlation of second degree between groundwater recharge and NDVI indicating increase in recharge with increase in NDVI values upto a certain level.

(b) Chemical and isotopic methods

Tracers Carbon-14 and Chlorine Mass Balance composite method

Glenn A. Harrington et. al. (2002) concluded that the application of the carbon-14 and chloride approaches to the arid Ti-Tree Basin in central Australia has revealed the magnitude and spatial extent of recharge from ephemeral rivers. The equations used to estimate recharge rates from carbon-14 data and the length scale over which they apply also rely on knowledge of the aquifer characteristics (e.g. porosity) and geometry. Richard Taylor et. al. (1996) concluded that the combined techniques reveal that recharge is restricted to the heavier rainstorms of the monsoons. The magnitude of the recharge estimate demonstrates a stronger dependence on the number of heavy rain events than on the total volume of rainfall.

Chlorine Mass Balance method

Jozsef Szilagyi et. al. (2011) concluded that the application of a water balance recharge estimation technique based on MODIS and ancillary climate data demonstrates that the mean annual recharge rate based on this method are consistent with independent estimates based on baseflow, groundwater modelling and chloride mass balance given their uncertainty ranges. The MODIS-based method may be applicable for estimating spatially distributed mean annual recharge rates in sandy areas of the world, where basic climate data (precipitation, air temperature and humidity, global radiation or sunshine duration) are available. Tianming Huang and Zhonghe Pang (2010) concluded that reduced groundwater recharge caused by land-use change can be estimated by comparing the chloride concentration in the soil water from the base of the root zone to the base of the chloride concentrated zone, for pre-converted and converted land uses, based on the chloride mass balance and using the unconverted land use as the background for comparison. Regional afforestation and other land-use conversions to vegetation with higher water demand may have caused soil-water depletion and solute concentration, and are, therefore, not favourable to groundwater recharge and ecosystem restoration. F. Manna et. al (2016) concluded that the application of this approach was exceptionally well-suited for this study area because of the extraordinarily large number of groundwater samples collected from a dense network of monitoring wells collected over three decades combined with a robust surface water drainage monitoring program. The analysis of tritium concentration in the groundwater indicates that recharge occurred at the shallowest monitoring wells assuming a plug downward flow rate of 0.2 m per year. It is also found that infiltration water slowly moves the aqueous phase of the contaminant mass stored in the unsaturated zone toward the water table is important for remediation plans. Felix Oteng Mensah et. al. (2014) concluded that the CMB approach performs well in a tropical setting in providing fairly accurate estimates of groundwater recharge for groundwater resources evaluation. Jacob Nyende et. al. (2013) concluded that replenishment of groundwater in the study area is entirely through precipitation, shallow underground waters have undergone evaporation and the evaporation line above the GMWL. Also the EARTH model analysis indicates that groundwater fluctuations are affected by the natural climate variations and anthropogenic influences.

Radiation-based method

The precision of estimation by radiation-based methods is very sensitive to variations of the parameters used in each method. Thus, the coefficients of the radiation-based methods need to be adjusted based on weather conditions of each province. Only if the radiation-based methods are used for suitable and specific weather conditions, the highest precision of recharge estimation is obtained.

(c) Numerical modelling and empirical methods

GROWA model

The Gaussian error propagation method is a usefully technique for analysing the influence of input data on the simulated groundwater recharge. The present uncertainty analysis showed that the BFI and precipitation uncertainties had the greatest impact on the total groundwater recharge error. This result is achieved by using a specific model and is therefore not simply transferable to other hydrological models. Furthermore, it has to be noted that this analysis has the character of a worst case study, since the climate parameter used in this study shows a significant correlation.

Frequency Domain Analysis

The contribution of different hydrogeological structures to the hydraulic response to recharge is indicated by the dependency of the transfer function amplitude on frequency. The variability of transmissivity and storage coefficient tends to decrease with scale, and the average estimates converge toward the highest values at large scale. The small-scale variability of diffusivities, which implies the existence of a range of characteristic

temporal scales associated with different pathways, is suggested to be at the origin of the unconventional temporal scaling of the hydraulic response to recharge at high frequency.

Numerical Modelling method

(i) Precipitation model

The strength of association is higher between soil moisture and precipitation compared to that between soil moisture and temperature. The model parameter is higher for those locations having higher clay content, whereas the parameter is lower for those locations having a coarse texture. This suggests that the signature of soil texture is manifested in the model parameter as reflected in soil moisture simulation curves obtained using the study approach. The result indicates the importance of soil texture information and the spatial transferability of the proposed Hydrometeorological approach.

(ii) Leaf Area Index

A physically based approach to simulate groundwater recharge for sandy unconfined aquifers in clod climates was developed. The method accounts for the influence of vegetation, unsaturated zone thickness, presence of lakes, and uncertainty in simulation parameters in the recharge estimate. It is capable of producing spatially and temporally distributed groundwater recharge values with uncertainty margins, which are generally lacking in recharge estimates, despite understanding of uncertainty related to recharge estimates being potentially crucial for groundwater resource management. However, the parameter uncertainty defined for the study area was of minor significance compared with inter-annual variations in the recharge rates introduced by climate variations.

MODFLOW model

The application demonstrates that an integrated SWAT-MODFLOW is capable of simulating the spatio-temporal distribution of groundwater recharge rates, aquifer evapotranspiration and groundwater levels and that it enables the interaction between the saturated aquifer and channel reaches, which plays an important role in the generation of groundwater discharge in the basin, especially during the low flow period. The comprehensive results demonstrate that the model is able to represent the integrated watershed modelling results that contain surface hydrologic components such as distributed recharge rates, groundwater levels and discharge, with or without well pumping. H. Hashemi et. al. (2014) concluded, it appears that the GW abstraction has the most substantial effect on GWL drawdown that needs to be taken into account in the water resources management plan. The methods used in this study are suitable for assessing the climate change impacts on GW for local-scale aquifer systems. GWL projection by MODFLOW, particularly in a sophisticated aquifer system, shows the great potential of recharge modelling to address the sustainable GW management through adaptation scenarios.

WAVES model with improvements

Russell S. Crosbie (2013) concluded that vegetation is not necessarily a strong determinant of the sensitivity of recharge to climate change as sensitivity differs based on the amount of historical baseline recharge and not necessarily vegetation type. Sensitivity of recharge to changes in rainfall is least for high baseline recharge and greatest for low baseline recharge. Sensitivity is greater than one, meaning that there is amplification with greater changes in recharge than changes in rainfall.

Empirical Formulae

The study shows that there is variability in climate parameters. The study also shows that the climate has a significant effect on groundwater resources, which is revealed from the rainfall variable; however, evapotranspiration and solar radiation have a relationship with each other.

Overall Discussion and Conclusions

The study reveals that the reasons causing the variability in groundwater recharge are ranging from uncertainties in recharge influencing factors to change in climatic conditions. The study also shows that the uncertainties in distribution of groundwater recharge occur differently in different regions, due to the impact of various factors such as change in climatic conditions, change in land use, soil types, etc.

Broadly, according to the present study the uncertainties and challenges could be shortly enumerated, as per grouping of their types, as below:

Methods with physical parameters

Using the distributed recharge from WetSpass in a steady-state groundwater model will improve the prediction of the simulated groundwater level and recharge and this will lead to a stable solution for the groundwater level and recharge areas. Sometimes, for simplicity an assumption needed to be considered such as changes in tree and plant phenology (i.e. lower or higher leaf or plant area index) under drought or climate change conditions translate into minimal changes in interception storage capacities. Since outputs from the model are grid maps and not the tabular values, it would be helpful to combine two or more grid maps. WetSpass is especially suited for studying long-term effects of land use changes on the water regime in a watershed. In the case of GRACE satellite, it only tracks changes in terrestrial water storage but not changes of individual hydrologic components e.g. surface water, soil moisture, and groundwater and hence practical application of GRACE data for local water resources management, especially nowcasting and forecasting is limited. Combination of process-based APLIS modelling and GIS data analysis, makes us able to provide spatio-temporal information of groundwater recharge and sub-surface flow dynamics also during varying hydroclimatic conditions for karst aquifers. Forecasting those changes at regional scales requires new modelling tools, such as ILHM, which take advantage of increases in computational power and the latest GIS and remote sensing datasets. Together, the two datasets i.e. the soil moisture data and water table data, allow for a holistic assessment of the groundwater recharge process from the ground surface through the unsaturated zone down to the water table. Quantifying the impact of climate change on groundwater resources requires a physically based approach, such as hydrologic model, for estimating groundwater recharge that includes all of the important processes in the hydrologic cycle, such as infiltration, surface runoff, evapotranspiration, and snowmelt. Analysis of aquifer systems in a region can be done by splitting the aquifers sub-region wise and model-based study of projected climate-change effects on recharge can be done. RIB model is suitable for shallow unconfined aquifer systems, under certain conditions such as sufficient data about long time series of groundwater level and rainfall available in similar regions.

Chemical and isotopic methods

Groundwater recharge is possibly the most important, but generally the most difficult, component of a water resource evaluation. Determining recharge rates in arid regions, where net water fluxes are extremely low, is particularly difficult because many of the techniques used to estimate recharge in wetter environments (e.g. water balance, applied tracers) can yield large uncertainties when applied to arid regions. Therefore, to determine recharge rates in arid and semi-arid regions, tracer approach proves to be extremely valuable. MODIS-based method, with ancillary data, may be applicable for estimating spatially distributed mean annual recharge rates in sandy areas of the world where basic climate data from the year 2000 and on are available. The uncertainty level of the resulting recharge-rate estimates can be easily defined from known or estimated levels of inaccuracy in the precipitation and evapotranspiration variables. Radiation method is best suited method to estimate potential evapotranspiration. Natural tracer method, which is based on baseflow recession, is applicable mostly in the large basins. EARTH model helps to determine the groundwater levels response to rainfall of the fractured aquifer.

Numerical modelling and empirical methods

The precipitation uncertainties have the greatest impact on the total groundwater recharge error and GROWA model, in which the Gaussian error propagation method is used, is best suited for analysing the influence of input data on the simulated groundwater recharge. For quantification of the recharge in fractured aquifers, frequency domain approach proved to be useful, considering its ability to handle the multi-scale heterogeneity and the range of temporal scales involved. SWAT-MODFLOW is a combination of two numerical models, which is capable of simulating a spatio-temporal distribution of groundwater recharge rates, aquifer evapotranspiration and groundwater levels and it enables an interaction between the saturated aquifer and channel reaches. MODFLOW method is suitable for assessing the climate change impacts on groundwater for local-scale aquifer systems. Computational methods to estimate groundwater recharge vary from simple water balance models, where water stores and fluxes are represented conceptually and related with adjustable parameters, to physically based models using Richards' equation to solve water fluxes through an unsaturated zone. A physically based method, such as LAI method, is useful for estimation of recharge for sandy unconfined aquifers. WAVES model uses three datasets i.e. climate, soils and vegetation and is applicable where sensitivity analysis is of importance.

Conclusions

In conclusion, it should be noted that realistic estimation of recharge depends mainly on identifying prominent features influencing recharge for a certain region and probable flow mechanism for targeted aquifer. Multiple dependent models / approaches needs to be applied and output could be compared with actual field conditions. The interaction of soil, with climate in the region, slope in the terrain, geology, geomorphology of the area, land use land cover, rainfall, drainage pattern and various other methods used for recharge determines the recharge quantity. The carbon-14 and chloride approaches have advantages over "conventional" numerical modelling approaches, because the degree of spatial parameterization required for the latter can generally not be matched by available data or understanding. Combination of three methods viz. Water table fluctuation (WTF), distributed hydrological budget (DHB) and hydrological budget (HB) proved to be a good example to know how to overcome the gaps in datasets and also the processing the datasets due to their limitations or gaps therein. Thus such combination of methods proved to be more reliable for estimation of groundwater recharge and also the impacts of the climate change on recharge. When these methods are coupled with remote sensing and GIS method, these combined methods are very useful and suitable as these are easy to use, cost effective, simple, requiring a few non-deterministic data such as groundwater level measurements, rainfall, aquifer properties, and groundwater extraction datasets.

It is also seen that whenever two or more methods or models are combined for bringing down the gaps in either datasets or the processing the datasets, helps to understand the uncertainties and encompass the maximum possible process components under one roof so as to take the challenge in estimating groundwater recharge rate under climate change scenario. Due to such combination of different methods or models relationship between different available hydrogeological and climate components can be assessed with great accuracy and can obtain better understanding of effects of climate change on groundwater recharge and also behaviour of groundwater recharge.

Combination of process-based modelling and GIS analysis allows circumventing the problem of data scarcity that most distributed models face and also can assess the impact of hydroclimatic extremes on groundwater recharge.

Table 1 Groundwater Recharge Estimation methods

Methods based on physical parameters	Chemical and Isotopic methods	Numerical modelling and Empirical methods
Water Budget	Stable Isotopes of Hydrogen and Oxygen	Runoff models
Base Flow Measurement	Groundwater Dating	Modelling based on unsaturated zone
Zero Flux Plane	Chloride Mass Balance a) Concentration method b) Flux method	Modelling based on saturated zone
Darcian methods	Environmental Tritium a)Peak Tritium b)Total Tritium	
Lynsimeters	Injected Tritium	
Water Table Fluctuation	Other Tracers	
Cumulative Rainfall Departure (CRD)		
Temperature Measurement		
Electrical Resistivity Measurement		
Gravity Recovery And Climate Experiment (GRACE)		

Acknowledgements

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Future Climate Projections for Annual and Seasonal Rainfall in Sri Lanka using CMIP5 Models

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Abstract:

Statistically downscaled data into 25kmx25km grid resolution of 6 earth system models under coupled model inter-comparison project 5 (CMIP5) are analyzed to see the future Changes in annual as well as seasonal Rainfall over Sri Lanka for 3 time periods; 2020–2040, 2040-2060 and 2070-2090 relative to baseline climatology period 1975-2005 for two emission scenarios; Rcp4.5 representing low emission and Rcp8.5 representing high emission scenario. The results of Rainfall changes are indicated that

- Annual rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts for the period 2020-2040 and positiveand increasing there after under RCP 4.5 scenario. Annual rainfall anomaly is positive and increasing for all 3 time periods under RCP 8.5 scenario .
- Southwest monsoon rainfall anomaly is positive and increasing inboth RCP 4.5 and RCP 8.5 scenarios with significant increase in rainfall over the wet zone.
- Northeast monsoon rainfall anomaly negative and negative trend is observed in RCP 4.5 and RCP 8.5. Decrease in rainfall is significant in the dry zone.
- First Inter Monsoon rainfall anomaly is negative in 2020-2040 , slightly negative in 2040-2060 and positive except Northeastern parts under RCP 4.5. First Inter Monsoon rainfall anomaly is negative in all 3 time periods under RCP 8.5 scenarios No significant trend is evident in RCP 8.5
- Second Inter Monsoon rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts in 2020-2040 and positive and increasing after that under RCP 4.5. Second Inter Monsoon rainfall anomaly is positive and increasing in 8.5 scenarios with increase in rainfall is significant in the Southwestern and Southeastern parts.

Introduction

Climate models are currently the most credible tools for making projections of future climate over the next 100 yr. A range of different climate models exist, from the simplest energy balance models to the most sophisticated global circulation models (GCMs; see, for example, McGuffie and Henderson-Sellers, 2004). Uncertainty in climate change projections include representation of the GHG emissions scenarios, uncertainties associated with future estimates of population growth, changes in land use, and the economic growth ect. Further uncertainties in climate modeling arise from uncertainties in initial conditions, boundary conditions, observational uncertainties, uncertainties in model parameters and structural uncertainties resulting from the fact that some processes in the climate system are not fully understood or are impossible to resolve due to computational constraints (IPCC, AR4).

The Intergovernmental Panel on Climate Change (IPCC) Fourth assessment report (AR4) stated that the current understanding of future climate change in the monsoon regions remains one of considerable uncertainty with respect to circulation and precipitation (IPCC AR4 Sections 3.7, 8.4.10 and 10.3.5.2).

Multi-model ensembles are defined in these studies as a set of model simulations from structurally different models, where one or more initial condition ensembles are available from each model and it is identified that projections have higher reliability and consistency when several independent models are combined (Doblas-

Reyes et al. 2003; Yun et al. 2003). Multi-model projections for long-term climate change were used in reports of the Intergovernmental Panel on Climate Change (IPCC), where unweighted multi-model means rather than individual model results were often presented as best guess projections (IPCC 2001).

According to previous studies, an increase in precipitation is projected in the Asian monsoon (along with an increase in interannual season-averaged precipitation variability) and the southern part of the west African monsoon with some decrease in the Sahel in northern summer, as well as an increase in the Australian monsoon in southern summer in a warmer climate. Differently from precipitation, Asian monsoon circulation was projected to decrease by 15 % (Tanaka et al. 2005; Ueda et al. 2006).

The main objective of this paper is to to develop CMIP5-based short-term (2030s representing climatology over 2021–2040), medium-term (2050s representing climatology over2041–2060) and long-term (2080s representing climatology over 2071–2090)climate change projections in Rainfall for Sri Lanka based on a multi-model ensemble of 6 models.

The remainder of the paper is organized as follows. Descriptions of the data and analysis method used are presented in section 2. In section 3, Future climate projections for annual and seasonal rainfall in Sri Lanka using CMIP5 models are investigated. Conclusion is presented in section 4.

Data and Methodology

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the CMIP5 and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5.

Table1Earth System models used to evaluate

CanESM2	The Second Generation Coupled Global Climate Model Canadian Centre for Climate Modelling and Analysis (2.8*2.8)
CNRM-CM5	National Centre for Meteorological Research/ Meteo-France (1.4 * 1.4)
CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Queensland Climate Change Centre of Excellence (QCCCE). (1.895*1.875)
GFDL-CM3	Geophysical Fluid Dynamic Laboratory NOAA, USA Coupled Climate Model (2 * 2.5)
MRI-CGCM3	Global Climate Model of the Meteorological Research Institute, Japan (1.132*1.125)
NCAR-CCSM4	National Center for Atmospheric Research, USA Coupled Climate Model (0.942 * 1.25)

Based on the model performance of historical runs NASA Earth Exchange Global Daily Downscaled Projections of 6 GCM models (CanESM2, CNRM-CM5, CSIRO-MK3-6-0, GFDL-CM3, MRI-CGCM3 and NCAR-CCSM4) with 25km grid spacing were used future projections for Sri Lanka(Herath.2016). Future change of precipitation for 3 time periods 20-year centered on 2030s, 2050s and 2080s (2020-2040, 2040-

2060 and 2070-2090) for 2 emission scenarios RCP 4.5 and RCP 8.5 were constructed by comparing climatological means during the historical run period (1975–2005). Spatial patterns of precipitation for all three futures are discussed on Seasonal and annual basis. Never the less this work is giving good initial idea about the future climate changes in precipitation over Sri Lanka.

Results

Three time slices incorporating 20-year centered on 2030s, 2050s and 2080s were examined to gain some insight into the range of future prediction of temperature and precipitation for Rcp8.5 and Rcp4.5 scenarios. Spatial patterns of precipitation and temperature for all three futures are discussed on Seasonal and annual basis. Never the less this work is giving good initial idea about the future climate changes in temperature and precipitation over Sri Lanka.
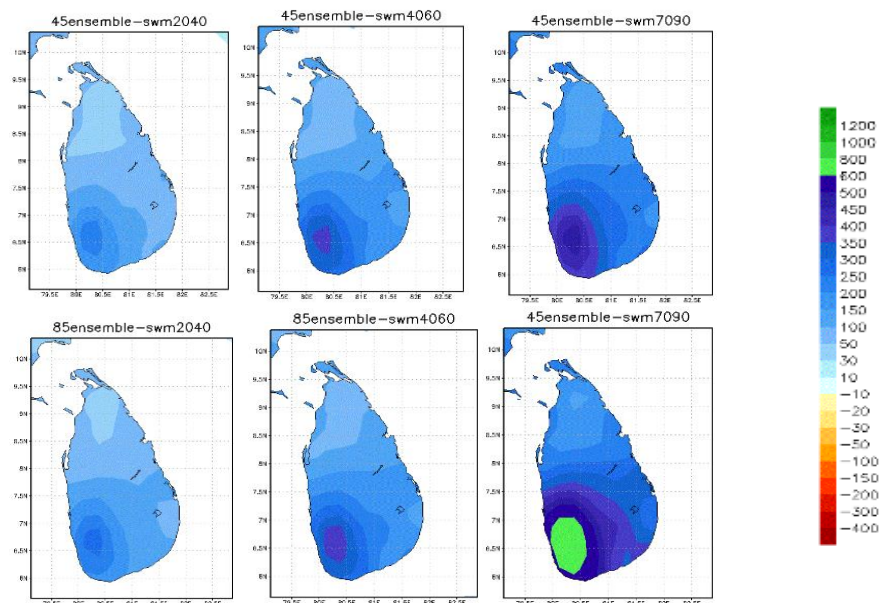
Figure1: Multi model ensemble of change in Southwest Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

For the period from 2020 to 2040 positive anomaly rainfall is predicted over most parts of the island by multi-model ensemble prediction under low and high (Figure. 1) emission scenarios.

For the period from 2040 to 2060, and 2070 to 2090 positive anomaly rainfall is predicted over most parts of the island by multi-model ensemble prediction under low and high (Figure.1) emission scenarios. Higher positive values are clearly apparent in the wet zone. It is evident that the intensity as well as areal extension of the positive rainfall anomaly over the wet zone increases with time (Figure. 1).
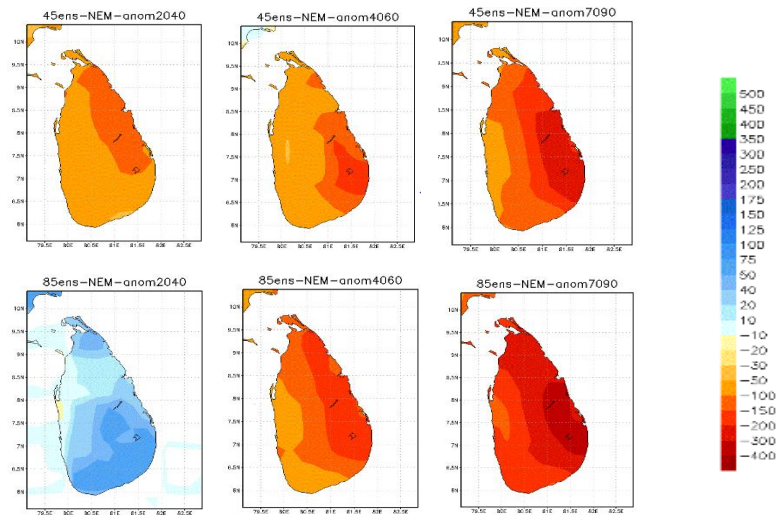
Figure2: Multi model ensemble of change in Northeast -Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

For Northeast monsoon season, the multi-model ensemble product predicted negative anomaly over the entire island under low emission scenario and slightly positive anomaly over the most parts of the island under high emission scenario for 2020-2040 period (Figure2).

For the period from 2040 to 2060, multi-model ensemble product predicted negative rainfall anomaly over the most parts of Sri Lanka for both low and high emission scenarios (Figure2).

For the period from 2070 to 2090, multi-model ensemble product predicted negative rainfall anomaly over Sri Lanka for both low and high emission scenarios with more negative values can be seen dry zone (Figure2).
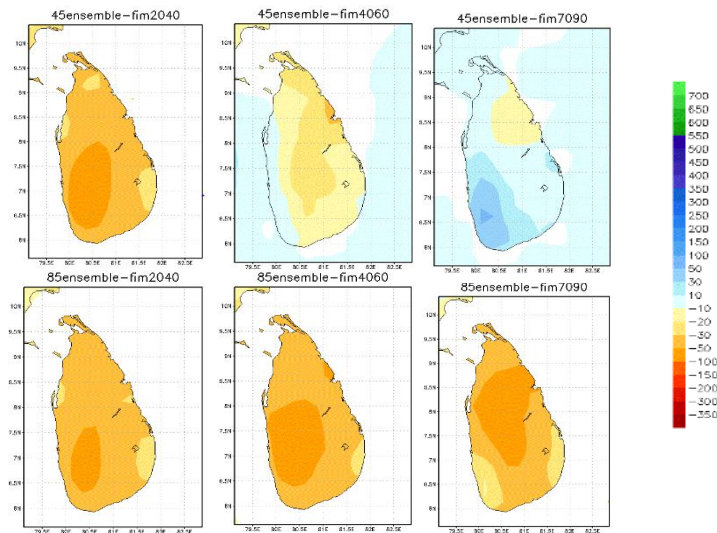

Figure 3: Multi model ensemble of change in First Inter-Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

When consider about the First inter monsoon season (Figure3), negative rainfall anomaly is evident in 2020-2040 period, slightly negative rainfall anomaly is evident in 2040-2060 period and positive rainfall anomaly is evident in 2070-2090 period according to the medium emission scenario. But according to the results of the high emission scenario it shows negative anomaly rainfall in 2020-2040, 2040-2060 and 2070-2090.
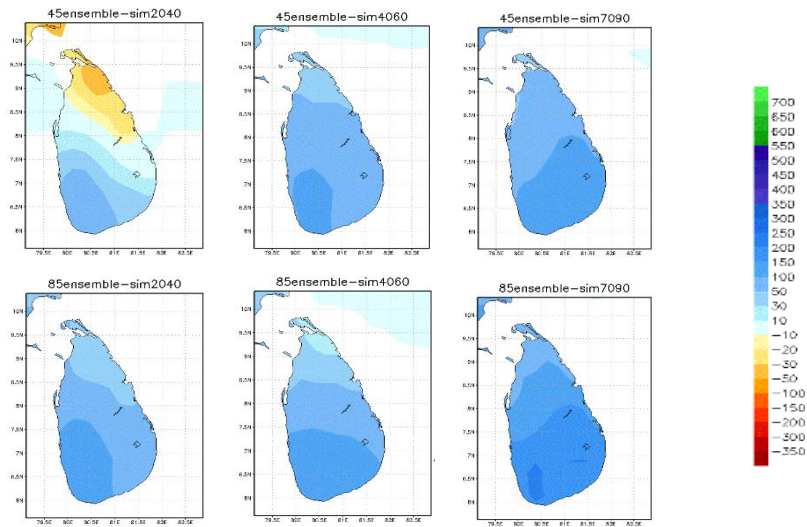
Figure 4. Multi model ensemble of change in Second Inter -Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

For second-inter monsoon season, the multi-model ensemble product predicted negative anomaly over the northeastern parts while slightly positive anomaly elsewhere (Figure4) for low emission scenario for 2020-2040 period. For high emission scenario, the multi-model ensemble product predicted positive anomaly rainfall over most parts of the island (Figure4) for 2020-2040 period.

For the period from 2040 to 2060, the multi-model ensemble product predicted positive rainfall anomaly over Sri Lanka for both low and high emission scenarios (Figure 4).

The multi-model ensemble prediction predicted positive rainfall anomaly over the entire country for 2070-2090 period under low and high emission scenario (Figure 4).
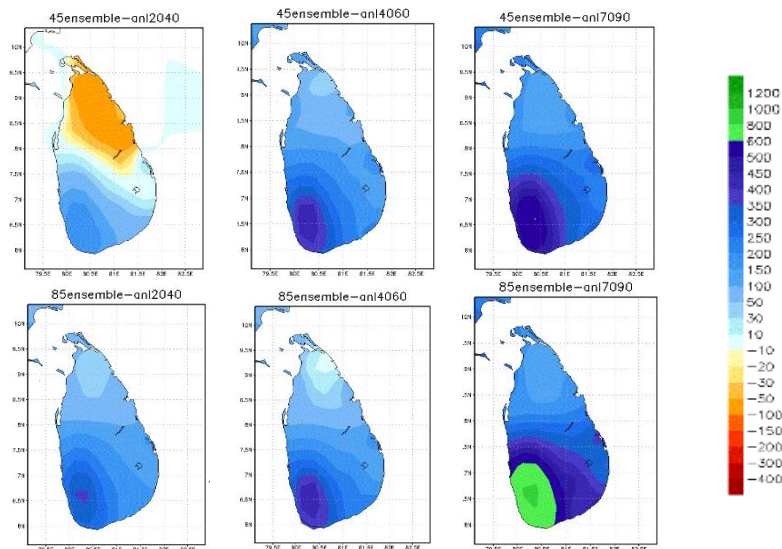

Figure 5: Multi model ensemble of change in Annual Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

The multi-model ensemble product indicated negative anomaly over the dry zone and positive anomaly over the dry zone for 2020-2040 period under low emission scenario. Multi-model ensemble predicted positive anomaly over most parts of the island for 2020-2040 period under high emission scenario (Figure 5). Increasing rainfall is significant over the wet zone in most models.

The multi-model ensemble product indicated positive rainfall anomaly over the entire country for 2040-2060 period under both low and high emission scenarios with significant increase in rainfall over the wet zone.

The multi-model ensemble product indicated positive rainfall anomaly over the entire country for 2070-2090 period under both low and high emission scenarios with significant increase in rainfall over the wet zone. Increase in rainfall over the wet zone is more significant in high emission scenario than high emission scenario.

The nonlinear and chaotic nature of the climate system imposes natural limits on the extent to which skilful predictions of climate statistics may be made. Model-based 'predictability' studies, which probe these limits and investigate the physical mechanisms involved, support the potential for the skilful prediction of annual to decadal average temperature and, to a lesser extent precipitation (IPCC, AR5 Synthesis report). Even though the Near-term (2020-2040) climate projections are important to decision makers in government and industry, the uncertainty during this period is high due to the climate is more reliance on the initial state of internal variability and less reliance on external forcing from emission scenarios.

Conclusion

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) data GCM 6 climate models (25-kilometer (km) grid resolution) were compared with model historical runs and observed data from 1975-2005 to evaluate model performance. NEX-GDDP downscaled models were captured the bi-modal pattern of annual cycle of precipitation in Sri Lanka as well as the spatial pattern of precipitation of annual average as well as seasonal average.

NEX-GDDP data of GCM 6 climate models were used to develop figurers climate projections.

The Representative Concentrated Pathways (RCP) RCP 8.5 and 4.5 scenarios from of the IPCC AR5 2013, representing high and medium futures, respectively, were adopted, with three time periods—2030s, 2050s, and 2080s.

The results indicated that the Annual rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts in 2020-2040, while Annual rainfall anomaly is positive and increasing thereafter under low emission scenario RCP 4.5.

Southwest monsoon rainfall anomaly is positive and increasing in both low (RCP 4.5) and high (RCP 8.5) emission scenario.

Northeast monsoon rainfall anomaly is negative for short term, medium term and long term projections observed under low emission scenario RCP 4.5.

Northeast monsoon rainfall anomaly slightly positive in short term term projection 2020-2040, and negative thereafter for medium term and long term projections under high emission scenario.

First Inter Monsoon rainfall anomaly is negative in 2020-2040, slightly negative in 2040-2060 and positive except Northeastern parts under low emission scenario RCP 4.5.

First Inter Monsoon rainfall anomaly is negative in all 3 time frames with no significant trend under high emission scenario 8.5.

Second Inter Monsoon rainfall anomaly is negative in in Northeastern parts, and positive in Southwestern parts in 2020-2040. Positive and increasing after that under RCP 4.5.

Second Inter Monsoon rainfall anomaly is positive and increasing in 8.5 scenarios with significant increase of positive rainfall anomaly over the Southwestern and Southeastern parts.

Acknowledgment

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