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Full Length Research Paper

Carbon stocks of Hanang forest, Tanzania: An implication for climate mitigation

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The study assessed carbon stocks of Hanang mountain forest, Tanzania. Thirty-four sample plots (40 × 50 m) were established along an altitudinal gradient. All trees with diameter at breast height ≥10 cm were identified and measured, and herb species and soil were sampled from four 1 × 1 m quadrats within 10 × 10 m subplots. Mean carbon stock was 48.37 and 0.26 t C ha^{-1} for tree and herb species, respectively. Soil organic carbon (SOC) was 64.2, 41.93 and 31.0 t C ha^{-1} in the upper, mid and lower layers, respectively. It was found that there was significant difference in tree carbon ($p<0.05$) along an altitudinal gradient. However there was no significant difference ($p>0.05$) in herbaceous carbon and SOC in the three layers along an altitudinal gradient. Tree carbon was low compared to other tropical areas where allometric models were employed. In contrast, SOC was high compared to other similar forests in the tropics. Anthropogenic threats will likely diminish the SOC hence conservation measures are needed.

Key words: Carbon, stocks, altitudinal gradient, soil organic carbon (SOC).

INTRODUCTION

Deforestation and degradation of tropical forests is estimated to contribute up to 17% of the global CO_2 emissions responsible for global warming, leading to climate change (Van der Werf et al., 2009). Climate change has direct consequences on the economy, ecosystems, water resources and sea level rise (IPCC, 2001). In recognition of the impacts caused by deforestation in developing countries, in the Conference of Parties (COP 13) in Bali it was agreed that reducing emissions from deforestation and degradation (REDD) should be included in a post-Kyoto mechanism (UNFCC, 2007). Recently UN also introduced REDD+ from the original concept of REDD to include emissions from deforestation and degradation of carbon-rich ecosystems (Burgess et al., 2010).

Tanzania took initiatives to implement REDD and REDD+ in 2008, and as part of results, there has been an established inter-ministerial REDD task force, a National REDD Framework document and a National REDD Strategy and Action Plan. To date, at least seven REDD+ pilot projects operates in Tanzania from which results will be applied to other areas in the country. Based on its experience with Participatory Forest Management (PFM),

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Tanzania REDD Readiness Preparation Proposal (R-PP) states that PFM will be the cornerstone of the national REDD+ program (URT, 2010; UN-REDD, 2011).The first proposed outcomes of the UN-REDD Programme in Tanzania that is, 2009-2011 are almost beyond its peak, yet baseline information for many forests including Hanang is still lacking. Taking into account the time factor and alarming rates of deforestation, this study is a viable option. The study aimed at providing quantitative information on the stocking characteristics and carbon stocks of Hanang mountain forest serving as part of baseline establishment for the ongoing REDD+ initiatives in the country.

Deforestation is responsible for the diminishing area of forests and woodlands in the country from the previous 35 million ha (URT, 1998) to 33.4 million ha reported recently (FAO, 2010). Some of these forests such as Hanang dominate volcanic highlands and it is the most isolated of the ancient volcanic mountains in the landscape of Eastern Africa (Krause and Böhme, 2010). Despite its potential for biodiversity conservation, water catchment and as carbon sink, high levels of forest degradation due to illegal lumbering and encroachment are threatening the future status of the forest. Deforestation and forest degradation is closely linked with low levels of carbon stocks hence increasing green house gas (GHG) emissions and subsequent global warming. Some studies have been conducted to determine stocking characteristics and carbon storage in Tanzania mainly along the Eastern Arc Mountains and Miombo woodlands (Munishi et al., 2010; Shirima et al., 2011). However, very little has been done for Hanang Mountain Forest.

Forest carbon is identified in three major pools that is, above and below ground living vegetation, dead organic matter and soil organic carbon (IPCC, 2006), whose quantities have been identified for few forest types in Tanzania (Munishi and Shear, 2004; Munishi et al., 2010). It is document that amounts of carbon stored in different forests and the extent of forest degradation on carbon storage are largely unknown for many forest types including Hanang in Tanzania (Burgess et al., 2007). Reliable equations for forest carbon measurements also exist for few forest types (Chamshama et al., 2004), mainly the Miombo woodlands (Munishi et al., 2010), and the Eastern arc mountain forests (Munishi and Shear, 2004). Due to lack of the needed scientific data this study is set to address the questions on stocking characteristics and carbon stocks of Hanang mountain forest, as part of the ongoing research towards climate change mitigation in the country. Specifically the study assessed the above ground biomass and carbon in trees, herbs as well as soil organic carbon. Non-destructive approach involving calculations from inventory parameters such as diameter at breast height (DBH), height, basal area and form factor, and then multiplying the volume with respective species wood basic densities. The soil basic densities were also used in the calculation of soil organic carbon.

MATERIALS AND METHODS

Study area description

Hanang mountain forest is found in Manyara region, within 4° 25' - 4° 35' S 35° 20' - 35° 25' W (Figure 1). It had been gazetted in 1936 with an area of ca. 5871 ha and covers an isolated volcanic peak extending from 1860 to 3418 m a.m.s.l. (Lovett and Pócs, 1993). The forest soils constitute the dark brown to grey brown humus rich loams over volcanic rocks, large area of the mountain being too steep to support vegetation (Kashenge, 1986). The climate has been described as oceanic rainfall with continental temperatures; also there may be some convectional rainfall from Lake Balangida. Nearest weather station in Katesh estimated rainfall amount of 750-1000 mm on the western side to 1200-1500 mm/year on the eastern side. Similarly, estimated >2000 mm/year at higher altitudes with a marked mist effect. During the dry season that is, between June and October, the estimated minimum temperature is 20.5°C (July) at lower altitudes. Forest vegetation occurs between 1980-3300 m with Montane and upper Montane forest on the wetter southern, eastern and northern slopes, and dry Montane forest on the western slopes (Lovett and Pócs, 1993).

Data collection methods

Sampling procedures and measurements

In order to understand the carbon stocks thirty four sample plots measuring 40 × 20 m (800 m^2 equivalent to 0.08 ha) were established at regular intervals along an altitudinal gradient. Plots were distributed along seven line transects to represent variations of conditions that influence the forest. Each sample plot was subdivided into 8 subplots each measuring 10 × 10 m (Figure 2). Four among the 8 subplots had nested quadrats each measuring 1 × 1 m and the remaining four subplots had 2.5 × 5 m quadrats in each. The sample plots adopted for this study were modified from 1 ha plots which were part of the tropical ecology assessment and monitoring (TEAM) protocol (Kuebler, 2006). The former (40 × 20 m) was adopted as trials for the countrywide programme on climate change impacts adaptation and mitigation (CCIAM) in Tanzania.

In each of the established 0.08 ha plots, all tree species with diameter at breast height (DBH) ≥ 10 cm were measured for DBH and height using diameter tape and suunto hypsometer, respectively. For the case of DBH, adjustments were done for the swollen tree bases, injured, fluted, crooked stems and other deformities (Malimbwi, 1997). Identification of the species was done in the field and samples of species that could not be identified in the field were taken to herbarium for further identification. Tree height and DBH data were used to calculate stocking parameters that is, density, basal area and volume. For carbon stock determination, multiplication of tree heights and plot basal areas with appropriate form factor was used to obtain tree volumes (Philips, 1995). Estimation of tree biomass was done by multiplying tree volumes with respective species wood basic densities (Munishi and Shear, 2004). Wood basic densities were obtained from samples of wood cores that were extracted from most frequent trees using an increment borer at approximately 1.3 m from the ground and some from the literature (Munishi, 2001). Tree data were converted into tree biomass per unit area (ha^{-1}). The tree carbon density was estimated as 0.50% of the biomass. The crown carbon was estimated using applicable biomass expansion factor (Munishi and Shear, 2004).

For determination of carbon stock in both herbaceous species and soil the samples were collected systematically within 1 m^2 quadrats nested in the sub-plots. Species were cut at the stem base, labelled and fresh weight recorded in the field (Munishi et al., 2010).

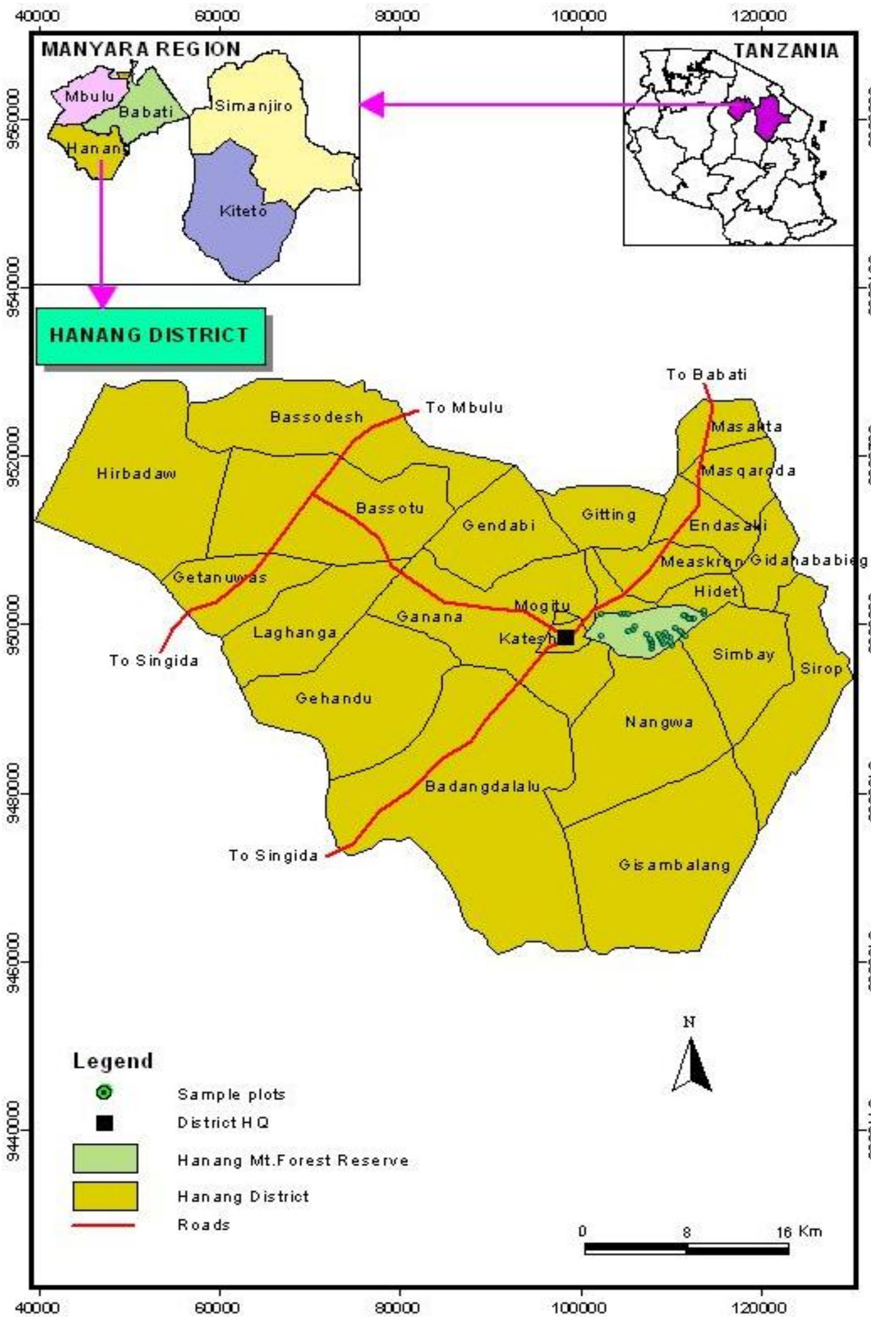

Figure 1. A map of Hanang District showing Hanang mountain forest.

Samples were taken for further laboratory analysis. Laboratory samples were oven dried at constant weight at 70ºC to obtain dry mass. The loss on ignition (LOI) method was used to convert the content of the herbaceous species into percent carbon (Anderson and Ingram, 1993). For determination of soil organic carbon, soil samples were collected within four 1 m^2 quadrats in which herbaceous samples were taken. Soil samples were collected between 0-15 cm, >15-30 cm and >30-45 cm depths using a calibrated soil auger (Munishi and Shear, 2004). A composite sample obtained by mixing soil from each of the four subplots that is, Q_1+Q_2 +Q_3 +Q_4 (Figure 2) was used. Walkley- Black method (Black et al., 1965) was used to determine the SOC. Computation of soil carbon density (tons ha^{-1}) was done on the basis of soil mass per unit area obtained as the product of soil volume and estimated soil bulk density (Munishi and Shear, 2004). Determination of SOC was done at the UDSM botany laboratory.

Data analysis

Data pertaining to tree carbon, herbaceous carbon and soil organic carbon were processed using MS Excel spreadsheet and analysed using one way analysis of variance (ANOVA) (Zar, 1984). Where necessary an alternative non-parametric test to ANOVA Kruskall Wallis Test was used.

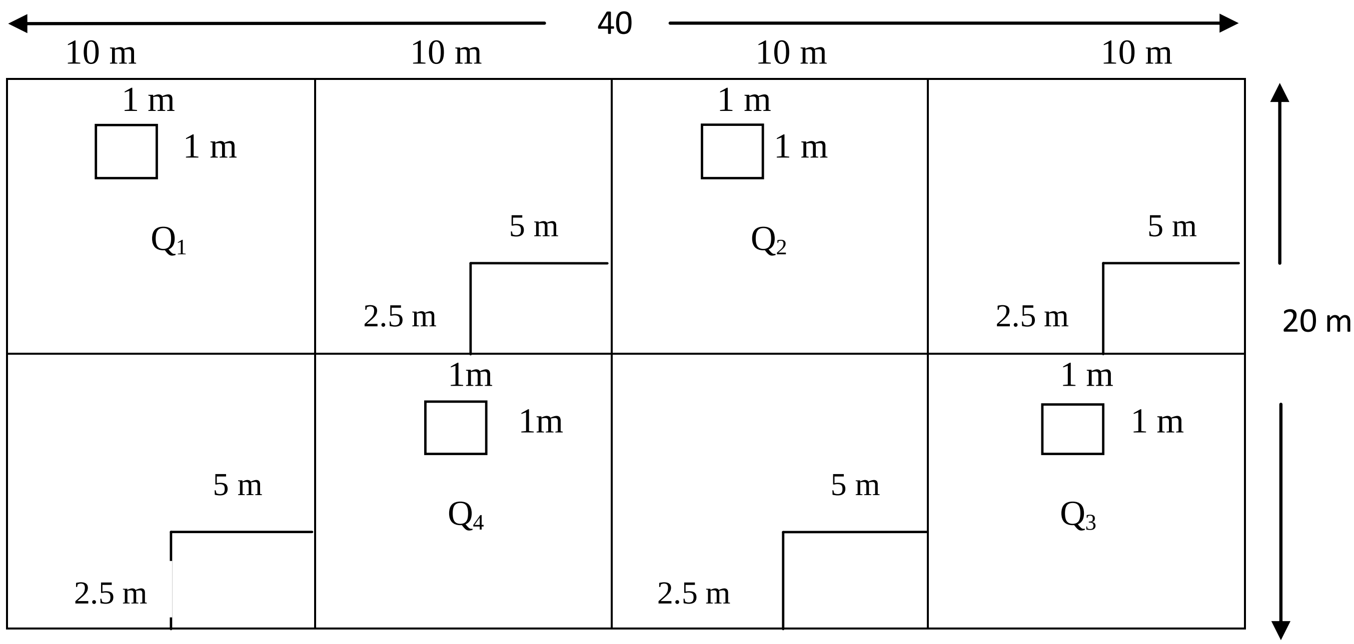

Figure 2. An illustration showing design of main plot and sub-plots.

Table 1. Above ground carbon values for tree species in Hanang FR.

Habit	DBH	Spp per Alt. Range	Alt. Range	Carbon (t/ha)	Whole forest carbon (t/ha)
Trees	≥10cm	36	L	71.46	
	≥10cm	33	M	49.83	**284,156**
	≥10cm	15	H	12.98	
	Mean tree carbon per ha			**48.37**	

Table 2. Above ground carbon values for herbaceous species in Hanang FR.

Habit	Spp per Alt. Range	Alt. Range	Carbon (t/ha)	Whole forest carbon (t/ha)
Herbs	21	L	0.22	
	36	M	0.28	**1,526.5**
	25	H	0.27	
Mean herbaceous carbon per ha			**0.26**	

RESULTS

Above ground carbon in tree species

Tables 1 to 4 summarises the results of carbon storage for various pools. Overall carbon in tree species was 48.4±8.0 t ha^{-1} equivalent to 48.4 × 3.67t COe ha^{-1} in the area, which resulted into 284,156 t ha^{-1} equivalent to 284156 × 3.67t COe ha^{-1} for the whole forest (Table 1). It was highest at low altitude (71.5 ± 17.0 t ha^{-1}), followed by mid altitude (49.83 ± 9.94 t ha^{-1}) and lowest at high altitude (12.98 ± 7.7 t ha^{-1}) (Figure 3a). Results indicated that there was a statistically significant difference ($p<0.05$) in tree carbon along altitudinal gradient (Table 4). The actual difference in mean scores between the groups was quite large. The effect size, calculated using eta squared was 0.30, hence indicating large effect. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the low altitude (*M*=10.79, *SD*=4.79) was significantly different from mid altitude (*M*=9.17. SD= 4.08) and high altitude (*M*=8.71, SD= 4.64).

Above ground carbon in herbaceous species

The mean herbaceous carbon (t ha^{-1}) reported from this

Table 3. Soil organic carbon values for three soil layers in Hanang FR.

Pool	Layers	Alt. Range	Carbon (t/ha)	Whole Forest C (t/ha)
Soil organic carbon (SOC)	0-15cm	1	66.5	**376,918**
	0-15cm	2	65.4	
	0-15cm	3	55.1	
Mean soil organic carbon per ha (upper layer)			**64.2**	
Soil organic carbon (SOC)	>30-45cm	1	31.2	**246,171**
	>30-45cm	2	35.0	
	>30-45cm	3	21.8	
Mean soil organic carbon per ha (middle layer)			**41.93**	
Soil organic carbon (SOC)	>30-45cm	1	31.2	**181,942**
	>30-45cm	2	35.0	
	>30-45cm	3	21.8	
Mean soil organic carbon per ha (bottom layer)			**31.0**	
Overall mean SOC of three layers for the whole forest				**805,031**

Table 4. Differences in carbon stocks for plants of different growth habits and soil.

Habit/Pool	Variable	N-Test	F	p-value	Remarks
1. Trees	Carbon	Ko, Sh	(2.33) 5.40*	0.01	Sig.
2. Herbs	Carbon	Ko, Sh	(2.32) 0.36	0.69	NS
	Carbon (Tl)	Ko, Sh	(2.33) 1.0	0.42	NS
3. Soil	Carbon (Ml)	Ko, Sh	(2.33) 1.73	0.19	NS
	Carbon (Bl)	Ko, Sh	(2.33) 2.61	0.09	NS

Ko, Komolgorov-Smirnov; Sh, Shapiro-Wilcox tests of normality; S-Test, Statistical test; one way ANOVA; Sig., Significant variation; n.s., No significant variation; values in parentheses indicate degrees of freedom. Tl, Top layer (0-15cm); Ml, Mid layer (>15-30cm); Bl, Bottom layer (>30-45cm).

study was 0.26 t ha^{-1} amounting to 1,526 tons of carbon for the whole forest (Table 2). However the observed differences in herbaceous carbon were not statistically significant along altitudinal gradient (Table 4).

Carbon variation among tree species

The amount of carbon also varied between different tree species. Species with highest carbon density in descending order were *Prunus africana*, *Cassipourea malosana*, *Ekebergiacapensis*, *Calodendrumcapense*, *Oleaeuropaea*, *Tecleasimplicifolia*, *Albiziaschimperiana*, *Eucleanatalensis* and *Maytenus senegalensis* (Table 5).

Relationship between carbon stocks and altitude

Relationship between carbon stocks and altitude in the trees, herbs and soil were analysed using Pearson correlation (Table 6). Results indicated that there was a statistically significant relationship between tree carbon ($p<0.05$) and altitude forming a slight negative correlation. However there was a positive relationship between the herbaceous species carbon and altitude, that was not statistically significant ($p>0.05$). On the other hand there was a negative relationship between SOC and altitude in all three layers, but the relationship was also not significant. From the results only basal area and tree carbon correlated negatively with the altitude.

Soil organic carbon (SOC)

Table 3 and Figure 3c, show the differences in SOC among layers of soil from the upper (0-15 cm), mid layer (>15-30 cm) and bottom layer (>30-45 cm). Overall mean SOC in the sampled area for the three soil layers was 64.20±3.03 t ha^{-1} (upper layer), 41.93 ± 2.0 t ha^{-1} (mid layer) and 31.0 ± 2.3 t ha^{-1} in the bottom layer. Mean SOC also varied between the three layers along the gradient such that it was highest in the upper layer (66.51 ± 5.94 t ha^{-1}) at the lower altitude, followed by mid altitude

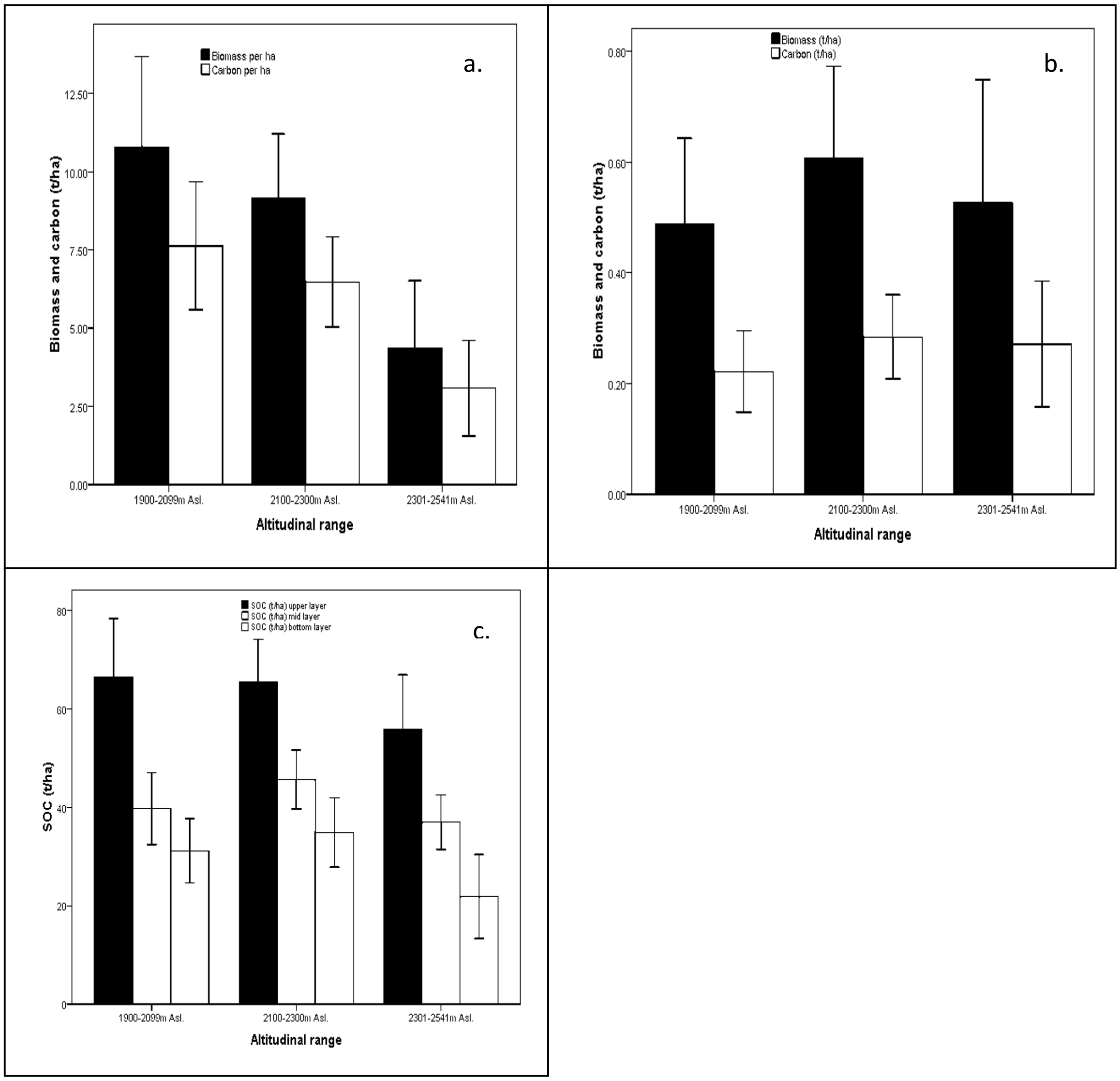

Figure 3. Biomass and carbon density for different growth forms and soil pools (a) trees (b) herbs (c) soil organic carbon (SOC).

(65.41 ± 4.36 t ha^{-1}) and high altitude (55.91 ± 5.49 t ha^{-1}). The mean SOC in the mid layer was much lower thanthe top layer such that it was 39.73 ± 3.64 t ha^{-1}, 45.62 ± 3.01 t ha^{-1} and 36.99 ± 2.75 t ha^{-1} in the low, mid and high altitude, respectively. The amount also decreased in the lower layer and the values were 31.17±3.30 t ha^{-1} in the low altitude, 35.0±3.53 t ha^{-1} in the mid altitude and 21.84±4.26 t ha^{-1} in the high altitude. However, there was no significant differences (p>0.05) in the SOC stocks for the three soil layers, respectively (Table 4).

DISCUSSION

Above ground carbon in tree species

The amount of 48.4±8.0 t ha^{-1} (Table 1) recorded for tree carbon, is lower compared to 517 and 388 t ha^{-1} reported earlier for Usambara and Uluguru Moutain forests, respectively (Munishi and Shear, 2004), 236.74 Mg C ha^{-1} reported for Moutain Makiling FR in Philippines (Lasco et al., 2000) and 118-306 t ha^{-1} also reported from Philippines (Lasco and Pulhin, 2003). It has been explained that reliance on allometric equations could be one of the limitations resulting in large variations in such estimates (Lasco et al., 2000). However a recent study in tropical forests in Thailand (Kaewkorm et al., 2011), reported a reasonable tree carbon stock of 24.79 and 50.58 t ha^{-1} in two forest sites which conform to amount reported by this study. The observed anthropogenic threats including previous logging, ongoing pit sawing, grazing and encroachment could be a reason for the low carbon amounts. Variations in the methods for calculation and sampling techniques used compared to other studies also could be a reason for the varying results.

Table 5. Altitudinal variations in carbon stocks for the most dominant tree species

Species name	Carbon per species (t ha^{-1})			Overall Carbon
	L	M	H	
Prunus africana (Hook.f.) Kalkman	154.89	57.84	0.00	212.73
Cassipourea malosana Alston	0.00	211.46	0.00	211.46
Ekebergia capensis Sparrm.	57.90	129.08	0.00	186.98
Calodendrum capense Thunb.	157.51	0.00	0.00	157.51
Olea europaea L.	61.76	78.24	0.00	140.00
Celtis africana Burm.f.	120.49	0.00	0.00	120.49
Teclea simplicifolia I. Verd.	34.27	65.79	0.00	100.06
Albizia schimperiana Oliv.	0.00	65.67	0.00	65.67
Euclea natalensis A.DC.	31.51	34.13	0.00	65.64
Maytenus senegalensis (Lam.) Ex	0.00	43.09	19.47	62.56
Ficus sp.	28.73	0.00	0.00	28.73
Protea petiolaris (Hiern) Bak.	0.00	0.00	28.04	28.04
Catha edulis (Vahl) Endl.	0.00	27.11	0.00	27.11
Apodytes dimidiata E.	18.76	0.00	0.00	18.76
Schefflera volkensii Harms	0.00	17.49	0.00	17.49
Clausena anisata (Willd.) Hook. f.	13.85	0.00	0.00	13.85
Ekebergia capensis Sparrm.	0.00	0.00	12.78	12.78
Hagenia abyssinica J.F.Gmel.	0.00	0.00	9.11	9.11
Nuxia congesta R.Br.	0.00	0.00	5.27	5.27
Lepidotrichilia volkensii (Gürke) J.	0.00	0.00	4.94	4.94
Cussonia spicata Thunb.	0.00	0.00	3.47	3.47
Pavetta lanceolata Eckl.	0.00	0.00	2.94	2.94
Maesa lanceolata Forssk.	0.00	0.00	1.72	1.72
Juniperus procera Hochst	0.00	0.00	1.50	1.50

[1]L=1900-2099m a.s.l., M=2100-2300m a.s.l., H=2301-2541m a.s.l.

Table 6. Results of correlation between various carbon pools with altitude

Habit/Pool	Dependent variable	Independent variable	Coefficient (r)	Ref. level (2 tailed)	p-value	Remarks
1. Trees	Carbon	Altitude	-0.46**	0.01	0.006	sig.
2. Herbs	Carbon	Altitude	0.19	0.05	0.28	NS
3. SOC	Carbon (Tl)	Altitude	-0.14	0.05	0.44	NS
	Carbon (ML)	Altitude	-0.07	0.05	0.69	NS
	Carbon (Bl)	Altitude	-0.16	0.05	0.40	NS

[a]richness based on absolute number of species, [b]richness based on Margalef's values
[+]all sample species evenness, [++]each sample species evenness, [*]correlation is significant at 0.05 level (2-tailed), [**]correlation is significant at 0.01 level (2-tailed), Sig. =correlation is significant, n.s. = no significant correlation, Tl= Top layer (0-15cm), Ml= Mid layer (>15-30cm), Bl=Bottom layer (>30-45cm)

Above ground carbon in herbaceous species

The reported amount for herbaceous carbon is lower compared to a mean 0.57 t ha^{-1} reported from a dipterocarp forest in Philippines (Lasco et al., 2006). However it was higher than a mean 0.07 t ha^{-1} reported from a secondary forest in Moutain Makiling FR in Phillipines (Lasco et al., 2004), also higher than 0.11 t ha^{-1} reported from a tropical forest in Eastern Panama (Kirby and Potvin, 2007). Despite the highest amount observed in the mid altitude and lowest in the low altitude, the observed differences were not statistically significant (p=0.53) along the altitudinal gradient (Figure 3b). There is higher limitation in the literature related to carbon storage by herbaceous species for many forests in Tanzania. Many previous studies have focused on quantifying carbon stock of tree species mainly in the eastern arc mountains and Miombo woodlands.

Relationship between carbon stocks and altitude

From the results only tree carbon correlated negatively with the altitude. However the relationship between herbaceous carbon as well as soil organic carbon and altitude for three soil layers was not statistically significant (Table 6). In a similar study conducted in Achanakmar-Amar-Kantak Biosphere Reserve in India, significant relationships against altitude were only observed for basal area and stem density, respectively (Sahu et al., 2008). In a study conducted in Southern Appalachian spruce-fir forest, soil carbon did not show a trend with altitude, likewise the carbon dynamics did not show a consistent pattern with altitude (Tewksbury and Miegroet, 2007). It was further pointed out earlier that ecosystem processes and attributes affecting soil carbon dynamics along elevation gradients are the product of long term interaction between climate, vegetation and soil type (Garten, 2004). However, various findings reviewed in the course of this study indicated limitation in studies examining the relationship between carbon stocks of different habits/ pools and altitude for montane forests in Tanzania. From these findings a complex of environmental factors apart from altitude including temperature, precipitation, edaphic factors, mineral contents and anthropogenic disturbances are also likely having an influence on the parameters that did not show significant relationship with altitude.

Soil organic carbon (SOC)

The mean SOC reported from this study, is lower compared to 246 t ha^{-1}(0-15 cm) and 176 t ha^{-1} (15-30 cm) reported earlier from Usambara and 246 t ha^{-1} (0-15 cm) and 176 t ha^{-1} (15-30 cm) from Uluguru afromontane forests (Munishi and Shear, 2004). The mean SOC for the whole forest area (5871 ha) that is, 805,031 t C is higher than mean SOC (554, 262 t C) reported from 6177 ha of a selectively logged dipterocarp forest in Phillipines (Lasco et al., 2006). The SOC amount in three layers that is, 137.13 t ha^{-1} is also higher than a range of 33-117 t ha^{-1} reported from the same forest in Philippines (Lasco et al., 2006), besides it is also slightly higher than the default value of 130 t ha^{-1} given by IPCC for volcanic soils (Lasco et al., 2004). However, it is lower than the mean SOC of 183 t ha^{-1} (upon conversion from Mg C ha^{-1}) reported from moutain Makiling FR in Philippines (Lasco et al., 2004). The total SOC obtained accounts for 72.9% of the total forest carbon including trees, herbs and soil hence preliminarily conforming to observed findings that below ground carbon in the tropical forests comprises 2/3 of the terrestrial carbon (Bolin and Sukumar, 2000; Lasco et al., 2004). Similarly studies in Tanzanian afromontane forests also reported higher amounts of carbon in the soil than for above ground biomass (Munishi et al., 2000; Munishi and Shear, 2004). Further studies are needed in the area to account for the amount of carbon comprising the leaf litter, dead wood and roots in Hanang Mt. Forest.

CONCLUSIONS AND RECOMMENDATIONS

Tree carbon stocks were relatively low compared to similar forests in the tropics especially where allometric models were employed. Herbaceous carbon was relatively higher compared to many areas where similar findings were reported elsewhere in the tropics. Existence of widely employed techniques for forest carbon estimation and the controversies underlying the actual methods to be adopted, affects reliability of the existing data on forest carbon stocks. Increasing application of allometric models contributes potentially towards forest carbon estimation. However the extent of its assumptions and limitations which tend to overestimate results as pointed in various studies impose many unresolved questions towards further research in the area. Existing soil organic carbon pools have potentially high amounts of carbon compared to similar areas in the tropics particularly in tropical Africa and Asia. However, ongoing threats from observed human activities such as pit sawing, pole harvesting, grazing and encroachment will likely diminish the SOC pools if effective measures will not be enforced. Further research should focus on quantifying the carbon content of the leaf litter, dead wood and root biomass. This will contribute towards a clear understanding of the existing carbon dynamics in the area.

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Full Length Research Paper

Species and breeding population of waterbirds on four islands in Kore Mosa in Persian Gulf in 2003 and 2012

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The research was conducted in Ghabre Nakhoda, Nedelghar, Dara and Boneh islands in Khore Mosa Ramsar site in the Persian Gulf from May to December 2003 and 2012. Total count method was used to obtain the census of the nests and breeding population of waterbirds on the Islands. Thirty three (34) species of waterbirds were identified, of which eight species were breeders. The maximum breeding population of Lesser Crested Tern *Sterna bengalensis,* Swift Tern *sterna bergii,* Caspian Tern *Sterna caspia*, Bridled Terns *sterna anaethetus*, Western Reef Heron *Egretta gularis* and Crab Plover *Dromas ardeola* were 2551, 124, 120, 1310, 23 and 10500 pairs, respectively. Only two pairs of Little Egret *Egretta garzetta* had been bred in 2003 in the Ghabre Nakhoda. The islands have been identified as an "important bird area" (as a part of Shadeghan marsh) by Birdlife International proposed for protection as a part of the wildlife refuge of Shadeghan and suggested for to be classified as sensitive habitat for breeding seabirds.

Key words: Breeding species, nest number, species diversity, Persian Gulf.

INTRODUCTION

There are 34 islands on northern part of Persian Gulf belonging to Iran, four of them are located in Khore Mosa Creek Ramsar site (30°17'58"N 48°56'51"E) in Khuzestan province, (Figure 1). These islands provide ideal breeding grounds for large colonies of seabirds, (Scott, 1995 and 2008; Evans, 1994; Behrouzi-Rad and Tayfeh, 2008; Behrouzi-Rad, 2008, 2013). The islands are also important for nesting sea turtle, including Hawksbill Turtle *Eretmochelys imbericata* (a globally threatened species) (Scott, 1995). In the other hands, several aspects of the ecology of waterbirds make them useful as bio-indicators. Frist, waterbirds have been shown to track environmental variations, at short (months) and long (years) temporal scales, and at both species and community level (Redon et al., 2008; Almarez and Amat, 2004). Second, because many species are top predators, several contaminants often accumulate along the tropic chain, such species may be used as indicators of changes occurring at lower tropic level (Matsinos and Wolf, 2003; Burger and Eichhorst, 2005). And third, either the waterbirds themselves or their prey are exploited by humans (for example, hunting and fisheries), so that hunting bags of waterbirds may be indicative of productivity in nesting or wintering areas (Miller et al., 1998) or breeding parameters of birds may inform on fish stock (Enoder, 2009).

On the other hand, to monitor a group of birds implies that there is a need for information on the population status or health that can only be met by collecting data, because every species has a range of conditions under which it thrives. Removal of any component of those conditions and the species disappears or no longer successfully reproduces (Wetland International, 2007). Thus the continued presence of a species is an indication that the environmental conditions which it requires remain. By choosing to monitor a set of species that require high quality environments, specialized habitats, or conditions that a

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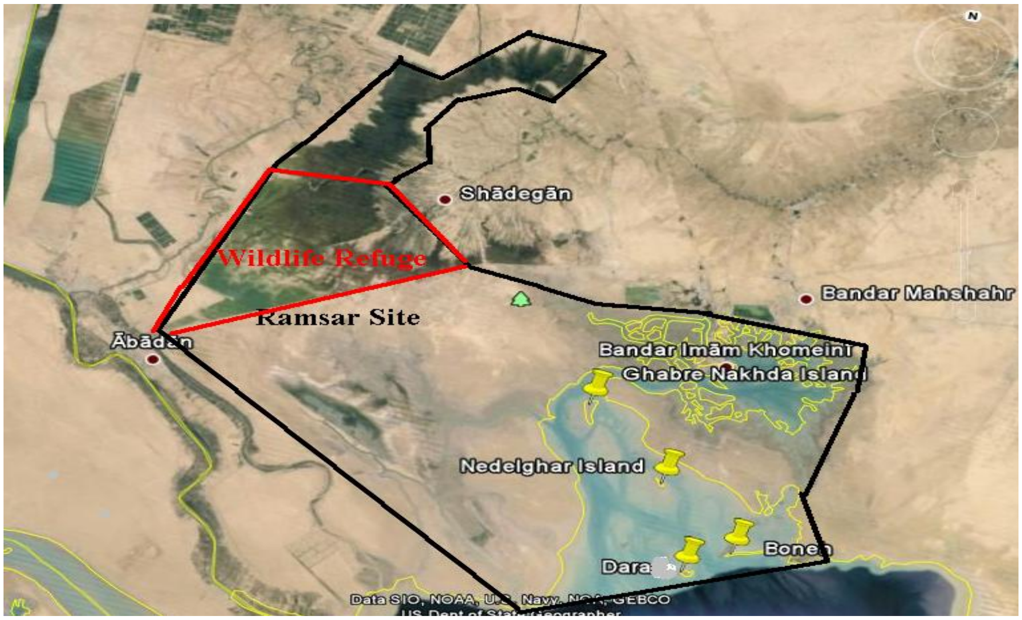

Figure 1. Location of Ghabre Nakhoda, Nedelghar, Boneh and Dara Islands in Khore Mosa in Persian Gulf.

manager may want to promote a sense of the region's environmental health can be made.

Since environmental or habitat health is often difficult for us to measure directly, due to the many factors (often unknown or ephemeral) that contribute to the conditions, it is often easier to measure the status of the breeding species that require them to develop an assessment. Also, it is widely accepted that the number of waterbirds using a site is a good indicator or that site's biological importance (Wetland International, 2007), and they are also important indicators of the ecological condition of their habitats. On the other hands, migratory waterbirds are one of the most remarkable components of global biodiversity.

This study was designed to obtain information on the presence, breeding species, breeding population and species diversity of waterbirds on the islands in 2003 and 2012, because of suggested classification as sensitive habitat for breeding waterbirds (Behrouzi-Rad, 2008).

MATERIALS AND METHODS

Study area

The study area located in Khore Mosa Creek near Bandar Imam (Imam Port) (30°17'58"N 48°56'51"E, Figure 1) and involves a particular natural habitats in Persian Gulf. Khore Mosa extends from Mahshahr port in the north, south to the Persian Gulf. This creek is 60 km totals in length and is a part of Shadegan marsh the Ramsar site. Khore Mosa Creek and small creeks around it are most important intertidal habitats of the Persian Gulf shoreline. There are 4 main islands in the Khore Mosa, named Ghabre Nakhoda.

The Ghabre Nakhoda Island located in middle of Khore Mosa (30°21'83"N 48°55'10"E) (Figure 1) and cover an area 4.2 to 500 ha, (Figure 2). There is a Grave in the middle of this island named Ghabre Nakhoda (Ghabr means Grave and Nakhoda meaning is Captain). The second island is Dara and located at the entrance of Khore Mosa Creek to Persian Gulf (30°06'06"N 49°06'06"E) (Figure 1) and cover an area 160 to 200 ha, (Figure 3).

Third one is located (30°08'25" N 49°09'21"E) 5 km far from west of Dara. This is the largest of the four islands, and a small village located on west part of the island (Figure 1). It is long and narrow, tow east and west margin of the island covered by density various plant species. Central part of the island is without any plant species. At low tide the area of the island is about 1500 ha. A small part on east margin of island is bare ground with less vegetation about one hectare. Usually waterbirds breeds on this part of the island (Figure 4).

There is another small island (less than two hectare and about 100 ha in ebb named Nedelgar, without any vegetation cover (30°14'90"N 49°02'86"E) (Figure 5). All four islands are flat, sandy and Shelly; 70 to 90% of area of the Dara, Ghaber Nakhoda and Boneh islands covered by vegetation in February and March (Figures 2, 3 and 4), but the Nedelghar is without any vegetation (Figure 5). All around the islands are mudflats. Main plant community of islands is *Atriplex*+ *Stipa*+ *Suaeda*+ *Halostachys*.

The main plant species of this community are *Atriplex leucoclada, Stipa capensis, Suaeda fruticosa, Halostachys belangeriana, Calanderula persica, Malva* sp., and *Cistanche tubolusa.* There is another plant community in Ghabre Nakhoda, *Calendula*+ *Cistanche*. Sandy soil rich in oyster shell are covered with this community.

Cistanche tubolosa is a vulnerable species in this community. *Calendula persica* is an endemic species. One of the main roles of this plant community is conservation a surface soil against erosion. In the undulating part of the islands, this community stabilizes the Crab Plover nests and provides a shelter over them.

All four islands are devoid of fresh water, uninhabited, hot in summer (45°C) and moderate in winter, their main inhabitants are the seabirds, but also sea turtles are present annually in spring and summer. These islands are propitious environment for nesting and breeding for migratory waterbirds as well as sea turtles.

Figure 2. Nesting sites and birds count area on Ghabre Nakhoda Island (Photo: Behrouzi-Rad, Feb. and Aug. 2012).

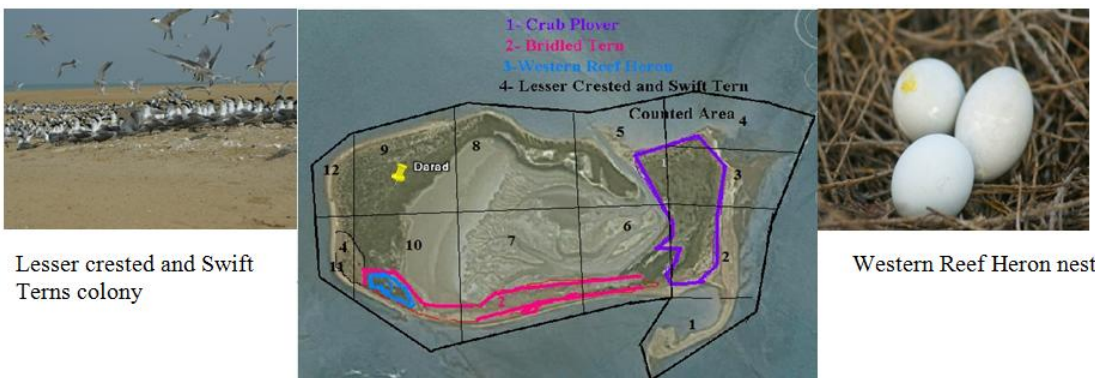

Figure 3. Study area, nesting sites and birds count routs on Dara Island (Number one to twelve are the squares that birds have been counted in them) (Photo: Behrouzi-Rad, Aug., 2003).

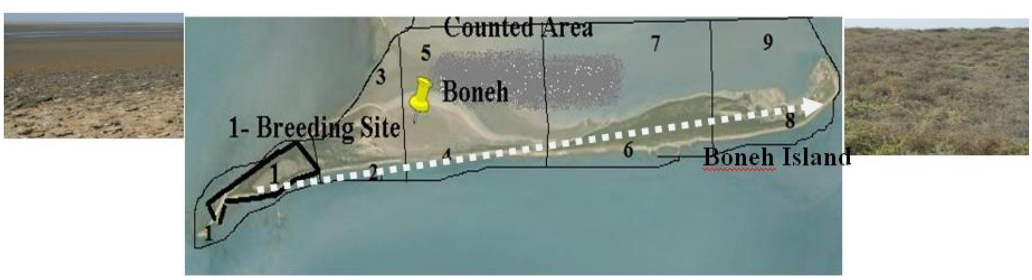

Figure 4. Study area, nesting sites and birds count rout on Boneh Island (Number one to nine are the squares that birds have been counted in them) (Photo: Behrouzi-Rad, Aug., 2012).

Breeding bird's population count

Nests of breeding species of waterbirds were counted directly on 20 August in 2003. The nests of Lesser Crested, White Cheeked, Caspian, and Swift terns (on sandy place of islands without any vegetation) and Western Reef Heron(on short bushes) were counted easily, because they were visible, (Figure 3), but for the Crab Plover, I counted holes (like tunnel) that had been made by this species for egg-lying. The nests of Bridled Tern were under the short bushes, and were counted by looking under the bushes. The non-breeders counted done on 15 may, 15 November and 20 December in 2003 by total count methods at low tide (Wetland In

Figure 5. Nedelghar Island and birds count rout on it (Number one to nine are the squares that birds have been counted) (Photo: Behrouzi-Rad, 2012).

ternational, 2007; Conway, 2005). The islands were visited 4 times again in May (10 to 11), August (2 to 3), November (6 to 7) and two days on December (12 to 13) in 2012. Total count method was used again for counting the birds and nests on islands as the same method in 2003 and number of nests multiplied in tow for getting the breeding populations of birds. The first observation was done on May 2003 and 2012. At this time breeding birds started to migrate to the islands. Second counted was done on August, which all breeding species established nests and laid egg. Third and fourth counts were done after breeding time on November and December in 2003 and 2012. All species observations around the islands were confirmed with binocular (10 × 40 mm).

Statistical analyses

Species diversity, percentage similarity, evenness and species richness between waterbirds communities, in 2003 and 2012 were measured by Simpson's, Shannon- Wiener, Menhink, Margalef and Brilouin indexes as fallow (Krebs, 2001).

Simpson's index diversity:

$$1 - D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)}$$

Where,
1-D = Simpson's index of diversity,
Ni = Number of individual of species i in the sample,
N = Total number of individuals in the sample = ∑ni,
S = Number of species in the sample.

Shannon-Wiener index as: H'=∑ (pi)(log2pi)

Where,
H' = Index of species diversity, pi=proportion of total sample belonging to i th species
Marghalef index: $= \frac{s-1}{lnN}$ S= Number of species and N= total number of all individuals
Menhink index = $\frac{s}{\sqrt{N}}$ S= Number of species and N=total number of all individuals in sample.

Brilouin Index: $\hat{H} = \frac{1}{N} \log\left(\frac{N!}{n_1!\, n_2! n_3! \ldots\ldots}\right)$

Where,
H=Brilouin index, N= Total number of individuals in entire collection,
n1= Number of individuals belonging to species 1,
n2= Number of individuals belonging to species 2, and

Evenness index $= \frac{D - D_{min}}{D_{max} - D_{min}}$

Where,
D = Observed index of species diversity,
Dmin = minimum possible index of diversity given S and N.,
Dmax = Maximum possible index of diversity given S species and N individuals

Percentage similarity:$P = \sum \text{minimum } (P_{1i} P_{2i})$

Where,
P = Percentage similarity between sample 1 and 2,
P1i = Percentage of species i in community Sample 1,
P2i = Percentage of species i in community sample 2

RESULTS

Species and populations of birds on the Ghabre Nakhoda Island

Thirty two species of waterbirds were identified in this island in 2003 and 2012, (Table 1). Four Larus species (non-breeding) were dominant during study months in 2003 and 2012 (Table 1). Maximum birds were counted on 19th August (12721 individuals), in 2003 and 6220 individuals in 9th August 2012, because at this time all the breeding birds were nested and present on island. Minimum number of birds was counted in November 2003 and 2012, because the breeding species of birds has left the island at this time. In total, 8591 birds were counted in 2003 and 6909 individuals in 2012 (Table 1). Comparing

Table 1. Waterbirds of 32 species recorded at Ghabre Nakhoda Island on May, August, November and December in 2003 and 2012 (Area 500 ha).

		Ghabre	Nakhoda	2003			Ghabre	Nakhoda	2012	
Species	**15th May**	**20th August**	**15th November**	**20th December**	**%**	**10th May**	**2sec August**	**6th November**	**12th December**	**%**
Phalacrocorax carbo	0	0	0	5	0.05	0	0	0	5	0.70
Sterna Bergii	132	235	1	0	4.28	23	205	1	1	3.32
S.Bengalensis	150	3045	5	0	7.24	121	2345	5	0	5.76
S. anaethetus	120	556	6	0	7.93	111	234	3	0	5.56
S.caspia	4	180	3	2	2.19	4	156	3	2	2.39
S.nilotica	3	2	6	0	0.12	3	2	4	0	0.13
S.repressa	0	12	0	0	0.13	0	11	0	0	0.16
Larus genei	34	343	32	245	7.61	34	343	32	172	4.40
L.ridibundus	23	34	122	245	4.93	23	34	122	421	8.68
L. canus	47	12	31	18	1.25	34	14	32	21	1.46
L.fuscus	43	12	141	285	5.6	10	21	151	201	5.54
Tringa totanus	9	12	0	15	0.42	7	11	2	8	0.41
T. stegnatilis	0	6	3	9	0.21	2	1	5	4	0.17
T. nebolaria	1	0	8	12	0.24	11	1	2	3	0.24
Egrtta gularis	11	28	8	15	0.71	9	14	6	15	0.63
E. garzetta	3	2	4	2	0.13	1	3	3	2	0.09
Ardea cinerea	12	3	4	13	0.37	13	1	3	6	0.33
Ricurvirostra avosetta	0	5	12	6	0.27	0	1	7	8	0.23
Haematopus ostralegus	0	3	12	5	0.23	0	1	7	3	0.16
Charadrius alexsandrinus	0	5	0	5	0.11	0	6	0	4	0.14
Ch. Dubius	0	1	13	6	0.23	0	1	11	6	0.26
Ch. Temminkii	0	0	4	6	0.11	0	0	4	8	0.17
Ch.minuta	12	4	6	11	0.38	14	1	2	15	0.46
Numenius arquata	8	8	16	16	0.59	1	12	5	8	0.38
N. phaepus	5	3	25	25	0.67	2	4	30	16	0.75
Tring hypolacus	1	7	0	0	0.93	1	6	1	5	0.19
Gallinago media	0	5	0	0	0.58	0	3	0	0	0.4
Caldris minuta	21	4	54	13	1.07	2	3	76	11	1.33
C. alpinus	0	3	8	3	0.16	0	5	9	8	0.31
Arenaria interpres	2	4	2	0	0.93	12	1	3	0	0.23
Xenus cinereus	0	2	6	0	0.93	0	1	4	0	0.07
Dromas ardeola	780	1120	4	16	22.35	650	870	1	23	22.34
Mountly waterbird total numbers species	1421 (16.54%)	5656 (65.83%)	536 (6.23%)	978 (11.38%)	100	1088 (15.74%)	4311 (62.39%)	534 (7.72%)	976 (14.12%)	100
Sum of four month			8591		-		6909			-
Monthly waterbird species totals	20	28	26	23	-	22	30	28	25	-
Waterbird population density*	2.84	11.31	1.07	1.95	-	2.17	8.62	1.06	1.95	-
Average population density*		4.29			-		3.45			-

these two number it shows that the number of waterbirds reduced (19.75%) in 2012 (Table 1). Eight species of waterbirds had been bred on Ghabre Nakhoda Island in 2003 and three species in 2012, (Table 2), reduction was

Table 2. Comparison of the Number of nests of waterbirds in 2003 and 2012.

Species	Ghabre	Nakhoda	Dara		Boneh		Nedelghar
	20th Aguust 2003	3th August 2012	20th August 2003	3th August 2012	20th August 2003	3th August 2012	2003 and 2012
Lesser crested Tern	2551	0	0	505	130	45	0
Swift Tern	124	0	0	46	12	8	0
Bridled Tern	310	154	1452	806	112	51	0
White Cheeked Tern	10	0	0	0	0	0	0
Caspian Tern	120	0	17	0	0	0	0
Western Reef Heron	44	12	14	18	0	0	
Crab plover	1420	1201	230	10500	0	0	0
Little Egret	2	0	0	0	0	0	0
Total nests	4581 nests in 4.2 ha	1367 nests in 4.2 ha	1713 nests In 160 ha	11875 nests In 160 ha	254 nests In 180 ha	104 nests In180 ha	0 nests
Number of Species	8	3	4	5	3	3	0
Nests density	1090.71 nests/ha	325.47 nests/ha	10.70 nests/ha	74.21 nests/ha	1.41 nests/ha	0.57 nests/ha	0 nests/ha

62.5%. Five Tern species, Lesser Crested Tern *sterna bengalensis*, Swift Tern *Sterna bergii*, Bridled Tern *Sterna anethetus*, Caspian Tern *Sterne caspia* and White Cheeked Tern *Sterna repressa* did not breed in 2012. Breeding population of Crab plover *dromas ardeola* declined from 1420 pairs in 2003 to 1201 pairs in 2012, reduction was 15.42%. Little Egret *Egretta garzetta* did not breed in 2012 (in 2003, 2 nest with four eggs in each of them was counted) (Table 2). Lesser Crested and Swift Tern had been bred in a mixed colony on sandy part on north of island, (Figure 2). These parts of island are dry during year and never drown under water even in high tide, (Figure 2). Area of this part of the island is about 4.2 ha.

Species and populations of birds on the Dara Island

Eighteen species of waterbirds were identified on the island in 2003 and 2012, (Table 3). Counting was done at low tide and the area of the island was about 200 ha. Dara is smaller than Boneh and Greater than Ghabre Nakhoda, with a chain of high vegetated dunce along its western and eastern margins and round the southern end. The central part of island covering by water during high tide is without plant (Figure 3). Southern margin of island covered by vegetation is a suitable place for breeding of Bridled Tern. Crab Plover breed on eastern part of the island. Nests of the breeding birds was counted at high tide and the area of island was 160 ha (Figure 3). Four species in 2003 and 5 species in 2012 had been bred on this island (Table 2). The Crab plover was the dominant breeder species and the breeding population of this species increased from 230 pairs in 2003 to 10500 pairs in 2012. Seventeen (17) pairs of Caspian Tern had bred in 2003, but were not bred in 2012. Lesser Crested and Swift Tern had not bred in 2003, but was bred in 2012 (Table 2).

Species and populations of waterbirds on the Boneh Island

Twenty three (23) species of watebirds identified on the Boneh during study months (Table 4). Three gull's species were dominant. The population of these species was 3142 in 2003 and 1110 individuals in 2012. Total number of waterbirds were 5243 in 2003 and reduced to 2380 individuals in 2012 (reduction was 54.60%). Average density of waterbirds population was 0.87 in 2003 and 0.39 in 2012. Reduction of the density was 55.17% (Table 4). Three species of Terns had been bred on the island, (130 nests of Lesser crested Tern in 2003 and 45 nests in 2012, 12 nests of Swift Tern in 2003 and eight nests in 2012, and 112 nests of Bridled Tern in 2003 and 51 nest in 2012 counted) (Table 2). All breeding species

Table 3. Waterbirds of 15 species recorded at Dara Island on May, August, November and December in 2003 and 2012 (Area of island was about 200 ha.).

Species	Dara 2003					Dara 2012				
	15th May	20th Aug.	15th Nov.	20th Dec.	%	10th May	2sec Aug.	6th Nov.	12th Dec.	%
Phoenicopterus ruber	0	6	119	0	1.76	0	0	131	254	2.03
Sterna Bergii	12	45	5	12	1.04	11	54	3	1	0.36
S.Bengalensis	43	56	2	0	1.42	0	13	4	0	0.89
S. anaethetus	134	2931	3	2	43.34	123	2122	5	3	11.91
S. hirundo	3	2	12	2	0.26	1	2	6	0	0.47
S.repressa	3	0	0	12	0.211	7	9	0	2	0.09
Larus genei	116	134	554	455	17.77	111	133	229	217	3.64
L.fuscus	23	123	327	432	12.77	51	77	231	423	4.13
L.ridibundus	118	165	333	0	8.69	82	94	171	182	2.79
Egrtta gularis	2	32	0	2	0.5	11	12	3	4	0.15
Egretta garzetta	0	0	0	1	0.01	0	0	0	2	0.01
Ardea cinerea	12	17	12	11	0.73	13	12	11	13	0.25
Ricurvirostra avosetta	0	0	21	12	0.46	0	1	12	14	0.14
Haematopus ostralegus	0	0	4	2	0.08	7	1	4	0	0.6
Numenius arquata	27	12	42	32	1.59	14	23	46	22	0.55
Numanius phaepus	13	16	15	11	0.77	24	11	20	6	0.32
Dromas ardeola	145	450	3	2	8.47	2352	11500	5	11	73.32
Arenaria interpres	3	0	0	0	0.04	0	0	2	5	0.37
Monthly waterbirds numbers total *	654 (9.23%)	3989 (56.31%)	1452 (20.49%)	988 13.94%)	100	2807 (14.84%)	14064 (74.26%)	883 (4.66%)	1159 (6.12%)	100
Monthly waterbirds species total	14	13	14	14	-	13	15	16	15	-
Sum of four month		7083			-			18913		-
Waterbird population density	3.27	19.94	7.26	4.94		14.03	70.32	4.41	5.79	-
Average density		8.85						23.63		-

Table 4. Waterbirds of 23 species recorded at Boneh Island on May, August, November and December in 2003 and 2012.

Species	Boneh 2003					Boneh 2012				
	15th May	20th August	15th November	20th December	%	10th May	2nd August	6th November	12th December	%
Phoenicopterus ruber	0	0	0	212	4.10	0	0	0	23	0.98
Egrtta gularis	13	4	5	2	0.46	5	1	0	2	0.34
Ardea cinerea	15	12	23	11	1.17	3	8	21	6	1.62
Egretta garzetta	11	2	3	5	0.40	3	8	0	4	0.64
Ardea cinerea	12	3	2	9	0.50	2	4	1	2	0.38
Sterna Bergii	23	324	43	11	7.75	231	340	54	6	27.00
S.bengalensis	17	41	21	8	1.68	2	53	11	0	2.82
S. anaethetus	56	302	12	12	7.38	132	124	40	12	13.17
S.hirundo	12	16	12	0	0.77	6	7	12	0	1.06
S.repressa	32	6	0	32	1.35	0	2	1	0	0.12
Larus genei	206	456	511	89	24.41	113	20	31	40	8.72
L. ridibundus	8	234	165	67	9.16	297	34	24	6	15.44
L. fuscus	156	576	642	32	24.41	412	51	65	17	23.32

Table 4. Contd

L. argentatus	102	86	148	4	5.57	3	5	11	2	0.89
Dromas ardeola	13	12	0	2	0.52	4	2	0	4	0.42
Caldris minuta	11	4	0	0	0.29	0	3	2	0	0.21
Numenius arquata	14	12	31	0	1.29	5	2	3	1	0.47
N. phaepus	106	24	42	3	3.38	5	6	8	2	0.90
Limnicolla falcinellus	0	11	13	0	0.47	3	2	0	0	0.21
Ch. Alexandrines	0	11	0	0	0.21	0	0	0	0	0.00
Tringa tetanus	13	18	23	1	1.06	6	10	5	7	0.20
R. avosetta	12	21	15	4	1.00	8	6	9	2	1.06
H. ostralegus	3	4	6	8	0.40	2	3	5	8	0.77
Monthly waterbirds Numbers*	835 (16.15%)	2179 (42.14%)	1717 (32.21%)	512 (9.90%)	100	1232 (52.71%)	682 (29.18%)	289 (12.36%)	134 (5.73%)	100
Sum of four month			5243		-			2380		-
Monthly waterbirds species total	21	22	18	18	-	19	21	17	17	-
Waterbird population density	0.55	1.45	1.14	0.34	-	0.82	0.46	0.20	0.09	-
Average density		0.87						0.39		

Counted was at low tide and the area of the island was about 1500 ha.

had been bred on western edge of the island (Figure 4).

Species and populations of birds on the Nedelghar Island

Fourteen species of waterbirds were identified during study month. Total number of waterbirds were 1183 in 2003 and reduced to 918 individuals in 2012, (reduction was 22.40%). Average density of waterbirds population was 2.95 in 2003 and 2.29 in 2012. Reduction of the density was 22.35% (Table 5). There is not any official report of breeding birds in this island. None of waterbird's species had been bred in 2003 and 2012. Sea Turtles only breeds on it.

Population trend of waterbirds on the islands

Breeding population of the Terns species and Western Reef heron on the islands reduced from 4898 pairs in 2003 to 1645 pairs in 2012. Average reduction was 66.41% (Table 6), but the breeding population of Crab Plover increased from 1650 pairs in 2003 to 11701 pairs in 2012. The main breeding population of this species had been bred on the Dara Island (10500 pairs, Table 2). Breeding population of this species became about 7 fold in 2012. Total count method detected a total of 22100 bird individuals in 2003 and 18360 individuals in 2012 that belong to 37 species. Comparing these two numbers, it shows that reduction was 16.92% in waterbird's population in 2012 (Table 7). Eight species had been bred on the islands in 2003, and five species in 2012, reduction was 37.5%. Generally, breeding pairs of seven species were reduced and only one species increased. Total numbers of waterbirds were 22100 individuals in 2003 and reduced to 18360 individuals in 2012 and reduction was 16.92% (Table 7).

Diversity is a major aspect of species structure in avian community. Ecological Methodology Analysis Software (Version 6) by (Krebs, 2001) was used to determine and compare the diversity of waterbirds in the study area in 2003 and 2012. The result shows that waterbirds have the considerable species diversity, richness (37 especies) and evenness. All diversity indexes were lower in 2012 than in 2003 (Table 8). Similarity of breeding population of waterbirds has been showed in Table 9 and Figure 6. The most similarity was between Ghabre Nakhoda and Dara in August 2012, (94.80% Table 9). Least similarity was between Ghabre Nakhoda and Boneh in 2003 and 2012(11.27%, Table 9). There was not any similarity between breeding species on Nadelghar and other three islands in August 2003 and 2012, because there was not breeding species in Nedelghar in 2003 and 2012. The non-breeding species of waterbirds on four islands were similar (P_{value} = 5%) together (99.97%) (Figure 6), but there was 16.92% reduction of waterbirds populaton (except Crab Plover, An increase of Crab Plover occurred throughout the islands, Table 3) in 2012, (Table 7). Also the biodiversity indexes of the waterbirds were more in 2003 than in 2012 (Table 8).

DISCUSSION

Over 100 bird species occur in Khor Mosa (Behrouzi-Rad, 2008; Scott, 1995), of these, about 90% are waterbirds, of these more than 30% were present in study area

Table 5. Waterbirds of 14 species recorded at Nedelghar (area was 100 hectare)Island on May, August, November and December in 2003 and 2012.

Species	Nedelghar 2003					Nedelghar 2012				
	15th May	20th August	15th November	20th December	%	10th May	2sec August	6th November	12th December	%
Larus genei	113	16	12	112	21.38	112	18	121	13	28.75
L.ridibundus	12	3	1	8	2.02	0	1	3	3	0.76
L. canus	123	112	123	114	39.89	31	111	19	115	3.06
L.fuscus	118	113	31	11	23.07	117	17	112	11	27.99
Tringa totanus	1	0	0	2	0.25	1	0	0	3	0.43
Tringa stegnatilis	0	1	2	6	0.76	3	4	1	0	0.86
Tringa nebolaria	3	3	4	1	0.92	0	11	0	4	1.63
Egrtta gularis	4	5	2	0	0.92	3	1	2	0	0.65
Egretta alba	1	0	1	0	0.16	1	0	0	0	0.10
Charadrius dubius	3	4	0	11	1.52	0	0	23	11	3.70
Ch. Temminkii	12	6	15	21	4.56	5	7	11	3	2.83
Ch.minuta	6	0	3	11	1.70	0	2	1	0	0.32
Numenius arquata	5	1	3	4	1.09	7	1	0	1	0.98
Numanius phaepus	6	2	0	12	1.69	1	0	5	2	0.87
Monthly waterbirds numbers total*	407 (34.40%)	266 (22.48%)	197 (16.65%)	313 (26.45%)	100	281 (30.61%)	173 (18.84%)	298 (32.46%)	166 (18.08%)	100
Sum of four month		1183			-			918		-
Waterbird population density	4.06	2.66	1.96	3.13		2.8	1.73	2.98	1.66	
Monthly waterbirds species total	12	11	10	12		9	10	10	10	
Average density		2.95						2.29		

Table 6. Variation of breeding pairs of waterbirds on four islands in 2003 and 2012.

species	2003	2012	Variable	Trend	Average reduction
Lesser crested Tern	2681	550	79.48%	Reduction	
Swift Tern	136	54	60.29%	Reduction	
Bridled Tern	1874	1011	46.05%	Reduction	
White Cheeked Tern	10	0	100%	Reduction	
Caspian Tern	137	0	100%	Reduction	66.41%
Western Reef Heron	58	30	48.27	Reduction	
Little Egret	2	0	100%	Reduction	
Total nests	4898	1645	66.41%	Reduction	
Crab plover	1650	11701	Increased 7 fold	increased	
Number of. species	8	5	37.5%	Reduction	37.5%

(Tables 1 to 4). Besides terns, which breed in summer, several other species of waterbirds use the islands for breeding, notably Crab plover *Dromas ardeola* and Western Reef Heron *Egretta gularis*. Bridled Tern, Lesser Crested Tern, Swift Tern and Crab Plover were dominant breeders in the islands in 2003 and 2012, (Table 2). The breeding population of terns reduced, but the breeding population of Crab Plover increased in 2012. All breeder species declined from 2003 to 2012, (4898 to 1645 pairs, (Table 6), except Crab plover increased from 1650 to 11701 pairs) the fluctuation depends on security and local environment factors of the study area. Dominant species (non-breeder) during study months were *larus* sp (*Laris genei, larus ridibundus* and *Larus fuscus*) in islands, but population of them declined from 2780 individuals in 2003 to 2001 individuals in 2012 (Table 3). The main reason of this reduction is haunts of fishermen and local environment factors on the islands. Total population (non-breeding) 22100 reduced to 18360 individuals (reduction was 16.92%). Comparing the similarity measure

Table 7. Variation of waterbird's population (non-breeding) on islands in 2003 and 2012.

Place	2003					2012				
	May	August	November	December	Total	May	August	November	December	Total
Nedelghar	407	266	197	313	1183	281	173	298	166	918
Boneh	835	2179	1717	512	5243	1242	691	303	144	2380
Dara*	654	3989	1452	988	7083	2807	3564	883	1159	8413
G. Nakhoda	1421	5656	536	978	8591	1088	4311	534	976	6909
Total	3317	12090	3902	2791	22100	5191	8730	2004	2435	18360 (16.92%) Reduction

Table 8. Species diversity, richness and evenness in 2003 and 2012 in the study area.

Diversity index	2003	2012
Dominance_D	0.413	0.414
Simpson_1-D	0.786	0.585
Shannon_H	1.952	1.341
Evenness_e^H/S	0.406	0.261
Brillouin	1.912	1.308
Menhinick	0.583	0.512
Margalef	2.527	2.159
No. species	21	22
Total	22100	18360

Table 9. Similarity of breeding waterbird's population in 2003 and 2012.

Place		Ghabre	Nakhoda	Dara		Boneh	
		20th August 2003	3th August 2012	20th August 2003	3th August 2012	20th August 2003	3th August 2012
G. Nakhoda	20th August 2003	100					
	3th August 2012	38.64	100				
Dara	20th August 2003	22	25.51	100			
	3th August 2012	42.56	94.8	20.37	100		
Boneh	20th August 2003	60.66	11.27	44.09	11.43	100	
	3th August 2012	52.74	11.27	49.04	11.43	92.09	100
Nedelgar	2003 and 2012	No breeding	No breeding	No breeding	No breeding	No breeding	No breeding

in Table 9 shows there is some difference between breeder species (8 species in 2003 and five species in 2012) and breeding population of waterbirds (4898 to 1645 pairs) in August 2003 and 2012. The Khor Mosa complex (Channels, islands, beaches, mudflats and sand hills) is the most important habitat for waterbirds in the Persian Gulf. For this reason, Khore Mosa complex was suggested for classification as sensitive habitat for breeding waterbirds, (Behrouzi-Rad, 2008), but egg-collecting, chick and female harvesting, when the females site on eggs are serious treats to the breeding population of terns and Crab Plover. Poaching is practiced particularly

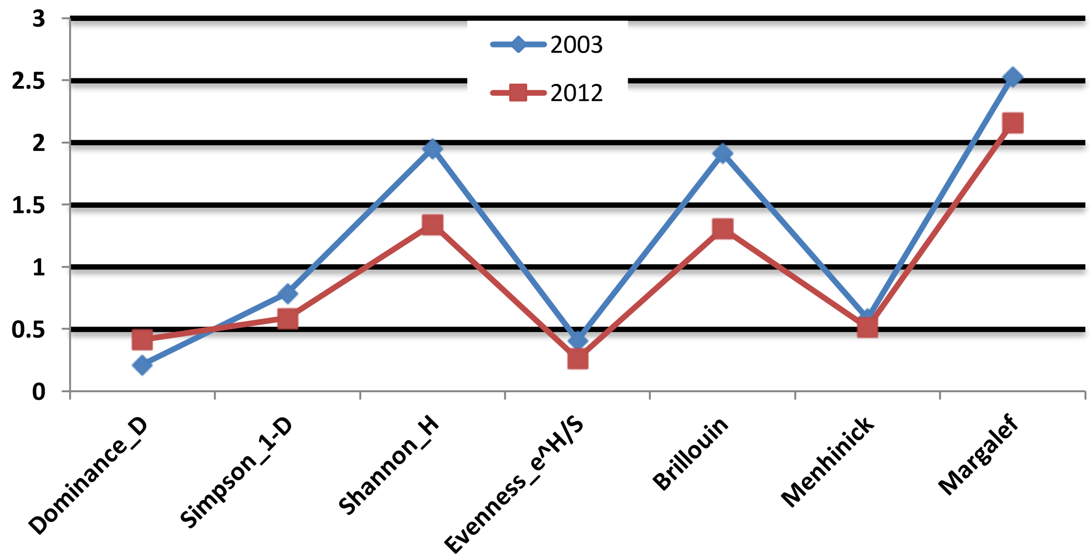

Figure 6. Measures of heterogeneity (95% confidence limits) birds in 2003 and 20012 in study area in non-breeding population.

on the islands. Oil pollution has been reported on the beaches around Bandar Mahshar in the southeast (Pandam, 2003; Behrouzi-Rad, 2013). The breeding success of the species is sensitive to food availability, predator presence, and human disturbance and oil pollutions in Khor Mosa, for these reasons Khore Mosa complex need to be protected during breeding season.

Conclusion

From this monitoring study, several conclusions can be made: This approach, of utilizing several methods to gather observations, provided enough records to monitor the Khore Mosa complex waterbirds population on islands. Considerable variation was noted in the number of breeding pairs from 2003 to 2012 (4898 to 1645 pairs).

Identification of essential roosting and nesting habitat required for sustaining seabird populations in a given region of conservation is needed to be given concern. Conservation problems and threats faced by seabirds in the region have been discussed elsewhere (Scott, 2007 and 2008; Evan, 1994; Tuck, 1974; Basson et al., 1977), but briefly these are included in offshore pollution, commercial exploitation of prey on which seabirds feed, incidental take, human disturbance, habitat reduction, and releasing waste water in water bodies. Seabird conservation is mostly a matter of island conservation.

Waterbird biology is useful indicators of environmental quality. Protection, management, and conservation of colonial waterbirds and seabirds can help conserve the broader landscape in which they occur. Wintering and other non-nesting habitats are critical to the long-term conservation of seabirds and colonial waterbirds.

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Full Length Research Paper

Phytosociological features and threat categorization of *A. heterophyllum* Wall. ex Royle and *A. ferox* Wall. ex Ser. in Kumaun Himalaya

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Alpine and subalpine regions of Kumaun Himalaya were surveyed qualitatively and quantitatively for the population study to determine the status of *Aconitum* ferox and *A. heterophyllum*. Low population density across the surveyed populations and restricted distribution to specific pockets indicates poor availability of the species in the study area. Illegal and over exploitation of these species pose threat to their existence. The present study clarifies the population structure of identified aconite species in Kumaun Himalaya. Observations reveal that on the basis of six attributes (that is habitat preference, distribution range, population size, use pattern, extraction trend, native and endemic species) used to assign threat categories, both the *Aconitum* species are endangered.

Key words: Endangered, Himalaya*,* Aconitum heterophyllum, Aconitum ferox, medicinal plant.

INTRODUCTION

Since time immemorial, Himalaya is famous for its rich plant biodiversity including a wide range of medicinal and aromatic plants. The variety of soils, topography and climatic conditions of the region provide very congenial conditions for growth and development of many therapeutically important medicinal plant species (Rawat, 2005). However, most of these MAPs are experiencing habitat destruction due to unscientific, over and irregular exploitation of plants, which resulted in very fast depletion as well as extinction of some medicinally important plant species (Rau, 1975). There are many species which have become threatened in several tracts and are found only in inaccessible hilly areas. Recently, CAMP (2003) assessed threat status of plant species in Uttarakhand in which *Aconitum ferox* Wall. ex Ser. and *Aconitum heterophyllum* Wall. ex Royle were assigned the critically endangered and vulnerable status respectively. Aconites are widely recognized for their medicinal importance in Indian System of Medicine (ISM). According to Red List Categories published by IUCN (1993), threatened species are having small geographic area, narrow habitat specificity, commonly sparse and geographically restricted to special habitat.

A. ferox (Vern. Meetha-Vish, Vatsanabh) (Plate 1) and *A. heterophyllum* (Vern. Atees) (Plate 2) belongs to the family Ranunculaceae. *A. ferox* is an erect herb with glabrescent stem and long, broadly ovate, cordate leaves. Distribution of this species is found between 3000 - 3600 ma.s.l. in Kumaun Himalaya (Figure 1). Tubers of the species are collected in the month of September-October and are used as remedy for stomach ache, fever, and indigestion by the aboriginals*. A. heterophyllum* (Vern. Atees) is an erect, tuberous herb found at the same elevation of *A. ferox* (Figure 1). Tubers are collected and dried during September-October and are used in diseases like diarrhea, fever, general body

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Plate 1. *Aconitum ferox* Wall. ex Ser.

Plate 2. *Aconitum heterophyllum* Wall. ex Royle.

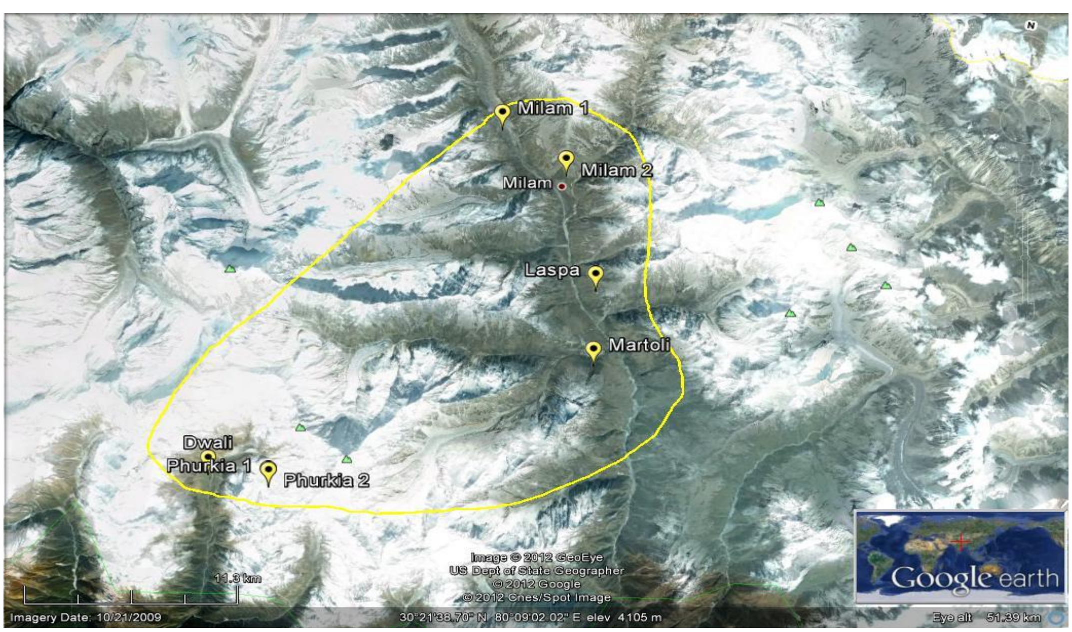

Figure 1. Map of study sites.

ache and also used as an aphrodisiac.

Till date, any assessment of threat categories to species in IHR is generally based on qualitative observations (Pangtey and Samant, 1988; Samant et al., 1993, 1996 a,b; Pandey and Well, 1997; Kala et al., 1998; Uniyal et al., 2002). Only a few studies have considered both qualitative and quantitative attributes for the assessment of species status (Airi et al., 2000; Nautiyal et al., 2002; Bhatt et al., 2007).

As quantitative infor-mation on a species plays a vital role in formulating a conservation plan and in understanding the ecology of the species (Uniyal et al., 2002), thus, the aim of the study was: a detailed survey of these aconites for quan-titative analysis throughout the Kumaun region. This is an attempt to provide quantitative details of *A. ferox* Wall. ex Ser. and *A. heterophyllum* Wall. ex Royle through assessment of the distribution patterns and quantum of availability. Also, it will provide essentially simple and assimilated data on current status of species population which can be used for assigning the categories of threat as suggested under IUCN Red List Categories (1993).

MATERIALS AND METHODS

Study area and methods

Field study

For the population assessment of these two species and their status in the study area fields surveys, vegetation sampling, vegetation analysis and quantitative analysis was done in 7 populations in sub alpine and alpine region, within three years from April 2008 to April 2011, during the peak season of flowering. The area surveyed included: Milam (Moraine) (P1- 4250 m), Milam (Fallow fields) (P2- 4178 m), Martoli (Pasture) (P3- 3974 m) and Laspa (P4-3669 m) and adjacent areas in Pithoragarh district; Phurkia (Scrub) (P5- 3260 m), Phurkia (Pasture) (P6-3150 m), Dwali (P7- 2790 m) in Bageshwar district (Figure 1).

Vegetation sampling and analysis

For the phytosociological study in every study sites, 30 quadrats of 1 × 1 m (1sq m) size at different altitudinal range were randomly laid (Misra, 1968). For population analysis and threat category determination, strands of 100 × 100 m^2 were identified and marked on each site. Vegetation sampling was conducted through vertical transect method (Michel, 1990). Since the distribution range is narrow and topography is diverse, approximately 60 m long and 30 m wide transect was laid in each strand. Transect were divided into 3 plots of 20 X10 m size as replicates and 10 quadrats of 1X1 m were laid randomly in each plot following Kershaw 1973. The threat category of a species was identified using six attributes (habitat preference, distribution range, population size, use pattern, extraction trend, native and endemic species) and following Samant et al. (1998) and Ved et al. (2003).

Quantitative analysis

The quantitative analysis such as density, frequency, and abundance of tree, shrubs and herbs species were determined as per Curtis and McIntosh (1950).

$$\text{Frequency} = \frac{\text{Total number of quadrats in which species occurred}}{\text{Total number of quadrats studied}}$$

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

$$\text{A/F ratio} = \frac{\text{Abundance}}{\text{Frequency}}$$

Pattern of the species was analyzed on the basis of abundance to frequency (A/F) ratio. Similarly relative values of frequency, density and dominance and Importance Value Index (IVI) were computed following the methods of Curtis (1959) as:

$$\text{Relative frequency} = \frac{\text{Percent frequency of species}}{\text{Total percent frequency of community}} \times 100$$

$$\text{Relative density} = \frac{\text{Density of species}}{\text{Total density of the community}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Total basal cover of species}}{\text{Total basal cover of the community}} \times 100$$

$$\text{Basal area} = \frac{(\text{Cbh})2}{4\pi}$$

Total basal cover (TBC) = Mean basal cover Density

Importance Value Index (IVI) = Relative frequency + Relative density + Relative dominance.

The species richness of the vascular plants was computed by using the method 'Menhinick's richness index (D_{Mn}) (Whittaker, 1977). The diversity index (H), was calculated by using Shannon-Wiener information Index (Shannon and Wiener, 1963). The concentration of dominance (Cd) was calculated by Simpson's Index (Simpson 1949).

Statistical techniques

Correlation between Density and Important value index (IVI) of the two species is computed through Carl Pearson's method. Regression has been subjected to density and important value index (IVI) of the study area. A curve that describes the distribution of probability over the values of a random variable is drawn with the help of Statistical Package for the Social Sciences (SPSS) software. Phytograph of both plant species is plotted to describe the phytosociological status of the plant using window 2007 'EXCEL' software.

RESULTS

Occurrence and availability

Performance details, at different altitudes, of identified taxa *A. ferox* is presented in Table 1. *A.ferox* grows well

Table 1. Phytosociological characters of *A.ferox* at different sites in Kumaun Himalaya.

Population	Altitude (amsl)	Habitat characteristics	Frequency (%)	Density (Ind/m^2)	Abundance	TBC (cm^2m^{-2})	IVI	Distribution Pattern (A/F ratio)
P1	4250	Glacial reverine and rocky moist area	50.00 ± 3.00	0.83 ± 0.16	1.14 ± 0.08	0.39 ± 0.20	6.63 ± 0.21	0.023
P2	4178	Alpine dry scrub, *Carex nubigena- Kobresia duthiei* community	56.67 ± 1.06	0.93 ± 0.13	1.22 ± 0.07	0.50 ± 0.05	7.58 ± 0.08	0.022
P3	3974	Open grassy alpine slope	46.67 ± 1.09	0.77 ± 0.18	0.92 ± 0.14	0.52 ± 0.06	6.91 ± 0.13	0.020
P4	3669	Shady moist alpine slopes	40.00 ± 1.00	0.60 ± 0.16	0.75 ± 0.07	0.42 ± 0.04	5.44 ± 0.26	0.019
P5	3260	Shady moist alpine slopes	60.00 ± 0.33	1.10 ± 0.16	1.83 ± 0.15	0.49 ± 0.15	7.75 ± 0.40	0.030
P6	3150	Forest edges, *Rhododendron* Forest margin	56.67 ± 1.13	1.07 ± 0.06	1.88 ± 0.11	0.54 ± 0.29	9.29 ± 0.14	0.033
P7	2790	Moist rock, *Quercus- Abies* forest margins	63.33 ± 0.69	0.93 ± 0.09	1.47 ± 0.27	0.37 ± 0.15	8.31 ± 0.07	0.023

P1, Milam (Moraine); P2, Milam (Fellow Fields); P3, Martoli; P4, Laspa; P5, Phurkia (Pasture); P6, Phurkia (Scrub); P7, Dwali.

in Shady moist alpine slopes. The density of *A.f erox* ranged between 0.60 individual / m^2 (P4) to 1.10 individual / m^2 (P5). The frequency of occurrence was varied between 40% (P4) to 63.33% (P7) and comparable to other associated species. The abundance to frequency (A/F) ratio of *A. ferox* revealed that species was distributed regularly in the five populations (P1, P2, P3, P4 and P7). Few other populations, P5 and P6 showed random distribution patterns (Table 1 and Figure 2).

A. heterophyllum showed best growth in natural habitat at two sites: P1 and P4. The density of *A. heterophyllum* varied between 0.21 individual / m2 (P4) to 0.62 individual / m2 (P6). The frequency of occurrence was relatively better (60% for P3 to 76.67% for P2, P4, and P7). The species largely prefers the southeast facing slope. Distribution pattern of *A. heterophyllum* shows that the species was distributed regularly in most of the populations (P2, P4, P5, P6 and P7); only two populations (P1, P3) showed random distribution (Table 2 and Figure 3).

A. heterophyllum

Considering that the IVI provides an excellent marker for determining the status of distribution and availability across varying environmental and biotic conditions (Negi et al., 1992; Ram and Arya, 1991), value of both identified taxa was compared. Values varied from one population to other. This difference can be attributed to varying species number, topography, biotic and abiotic interferences in community (Nautiyal, 1996). *A. ferox* had maximum IVI at P6 (9.29) in forest edges, *Rhododendron* forest margin while it was recorded minimum in P4 (5.44) where habitat was shady moist alpine slope. *A. heterophyllum* showed maximum IVI value of 9.70 in P2 and lowest value of 7.76 in P5. Phytograph of each species (Figures 4 and 5) was drawn to clarify the phytosociological attribute of the species.

Diversity Indices

Table 3 depicts the plant species richness (MeI), Shannon- Weiner diversity index (H'), and Concentration of dominance (Cd) of seven sampling plots in different forest patches of study area for both species. The adjusted Shannon-Wiener Index is the percent of the maximum possible diversity. It varied from 2.96 - 2.97 for *A. ferox* and 2.89 - 2.91 for *A. heterophyllum* in different alpine habitats. The low diversity was in single species dominant and low grazing pressure communities, and high in the case of moderately grazed communities. The Menhinick's richness

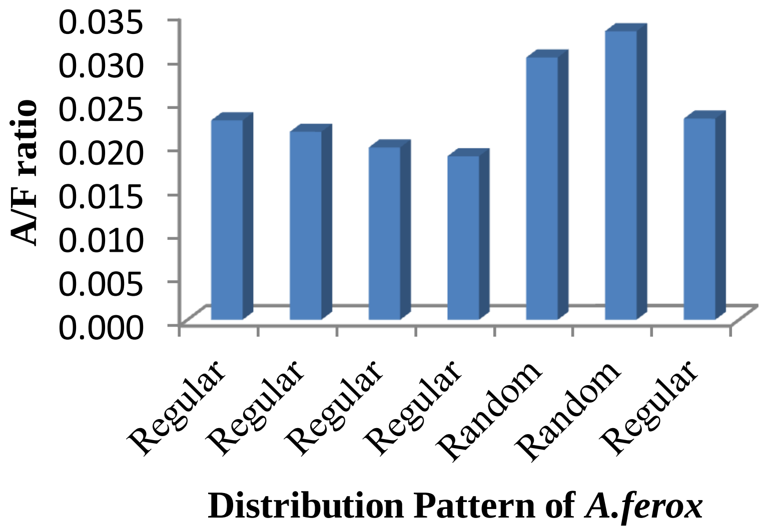

Figure 2. Distribution Pattern of *A. ferox.*

varied from 0.49 - 0.57 for *A. ferox* and 0.55 - 0.60 for *A. heterophyllum*. Concentration of dominance represents the different biodiversity. It ranges from 0.052 - 0.054 for *A. ferox* and 0.056 - 0.058 for *A. heterophyllum*.

In order to check the dispersal of both species, the normal probability curve (NPC) has been plotted for species richness against normal distribution. The plotted points do not fit the line well, and curve away from it in places; it is a non normal distribution. It indicates that the distribution of both species in selected sites is skew (Figures 6 and 7).

Regression

Regression has been subjected to density and IVI of both the species. Significant positive correlation was found between both the characters that density and IVI at $p<0.001$ level of significance. Density was taken as independent variable and IVI as dependent. Regression equation for A.ferox is $y = 6.2195x + 1.8808$, R square is 0.7621. For A. heterophyllum regression equation was $y = 0.3728x + 8.6001$, R square is 0.0043. From this equation relation between density and IVI can be calculated in the natural habitat.

Threat categorization

An area-specific threat categorization of species is very important for short or long-term management planning. The information, thus generated, has immense potential for contributing in threat categorization, conservation and management of threatened plant species (Hutchings, 1991). On the basis of the above interpretations and following Samant et al. (1998) and Ved et al. (2003), threat category of the species was identified using six attributes (habitat preference, distribution range, population size, use pattern, extraction trend, native and endemic species). In the present study, both the species of aconite, namely *A. ferox* and *A. heterophyllum* seems to be endangered in Kumaun Himalaya while assessed as critically endangered and vulnerable by CAMP (2003). These observations would also be helpful in determining the status of other species and can be applied for conservation strategies.

DISCUSSION

Low seed viability, obstruction of reproductive phases by juvenile, fronts and early snow fall coupled with biotic interference prevents seed maturation and reduced plant population in most of alpine vegetation (Pandey et al., 1997); hence they emerge through underground parenting organs (tubers). Studies on quantitative assessment play a vital role in the ecology of the species (Uniyal et al., 2002). It helps in determining the performance of populations under different sets of conditions and provides desired information about the specialized ecological requirements of a taxon (Kaul and Handa, 2001). The information, thus generated quantitatively clears that population of *A. ferox* and *A. heterophyllum* is severely fragmented (low population density and restricted distribution of species). This has conservation implications because species with specific habitat requirements have greater possibilities of extinction than species with a broad habitat range. In addition, a minimum population size is required for the long-term viability of threatened species (Cunningham and Saigo, 1999). Considering the higher frequency of occurrence in some populations is indicative that species

Table 2. Phytosociological characters of *A.heterophyllum* at different sites in Kumaun Himalaya.

Population	Altitude (amsl)	Habitat characteristics	Frequency (%)	Density (Ind/m^2)	Abundance	TBC (cm^{2}m^{-2})	IVI	Distribution Pattern (A/F ratio)
P1	4250	Glacial revarine and rocky moist area	63.33 ± 0.98	1.07 ± 0.21	1.68 ± 0.11	0.40 ± 0.06	9.29 ± 1.82	0.026
P2	4178	Alpine dry scrub, *Carex nubigena- Kobresia duthiei* community	76.67 ± 3.34	0.93 ± 0.07	1.22 ± 0.09	0.54 ± 0.03	9.70 ± 1.02	0.016
P3	3974	Open grassy alpine slope	60.00 ± 2.00	1.03 ± 0.13	1.72 ± 0.08	0.38 ± 0.05	8.06 ± 1.01	0.028
P4	3669	Shady moist alpine slopes	76.67 ± 3.32	1.07 ± 0.34	1.39 ± 0.15	0.21 ± 0.05	8.72 ± 0.28	0.018
P5	3260	Shady moist alpine slopes	66.67 ± 0.76	0.77 ± 0.13	1.15 ± 0.09	0.30 ± 0.05	7.76 ± 1.37	0.017
P6	3150	Forest edges, *Rhododendron* Forest margin	70.00 ± 1.13	0.73 ± 0.09	1.05 ± 0.10	0.62 ± 0.06	9.46 ± 0.86	0.015
P7	2790	Moist rock, *Quercus- Abies* forest margins	76.67 ± 1.20	0.97 ± 0.18	1.26 ± 0.09	0.49 ± 0.06	9.66 ± 1.00	0.016

P1, Milam (Moraine); P2, Milam (Fellow Fields); P3, Martoli; P4, Laspa; P5, Phurkia (Pasture); P6, Phurkia (Scrub); P7, Dwali.

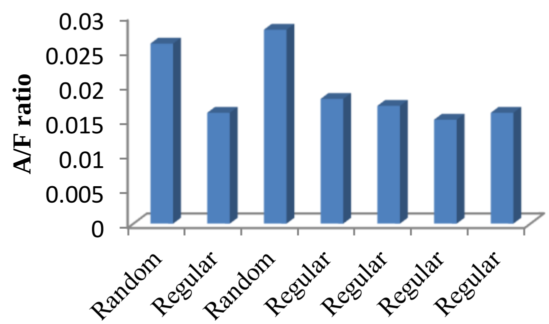

Figure 3. Distribution Pattern of *A. heterophyllum.*

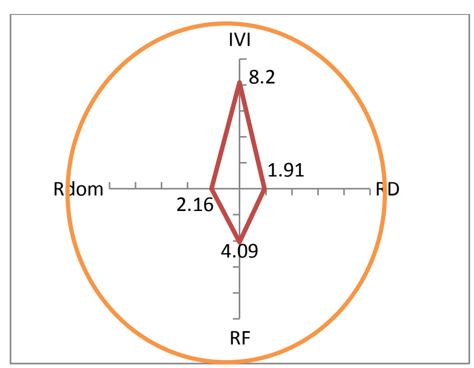

Figure 4. Phytograph of *A. ferox.*

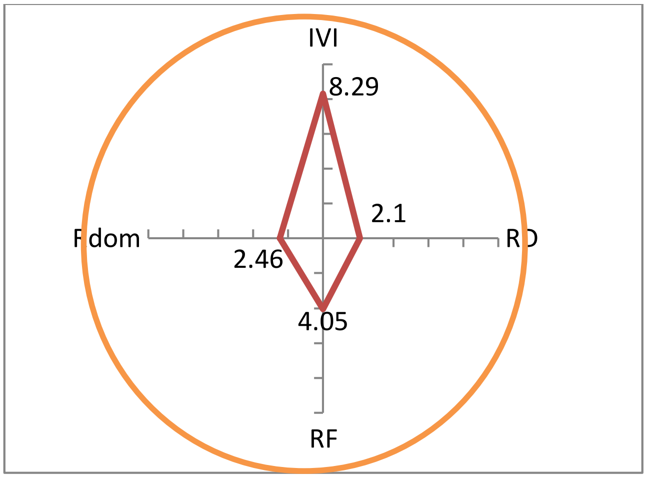

Figure 5. Phytograph of *A.heterophyllum.*

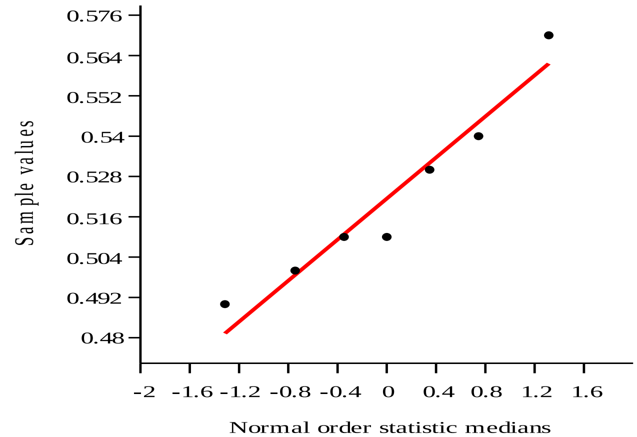

Figure 7. Dispersal species of *A. heterophyllum* through NPC.

Table 3. Diversity indices of sampling plots for *A.ferox* and *A. heterophyllum.*

Site code	*A. ferox*			*A. heterophyllum*		
	Cd	H'	MeI	Cd	H'	MeI
P1	0.052	2.97	0.51	0.056	2.91	0.57
P2	0.052	2.96	0.49	0.056	2.91	0.58
P3	0.054	2.97	0.57	0.056	2.91	0.57
P4	0.052	2.97	0.53	0.056	2.90	0.60
P5	0.053	2.96	0.54	0.056	2.91	0.56
P6	0.053	2.96	0.51	0.056	2.91	0.55
P7	0.052	2.97	0.50	0.058	2.89	0.57

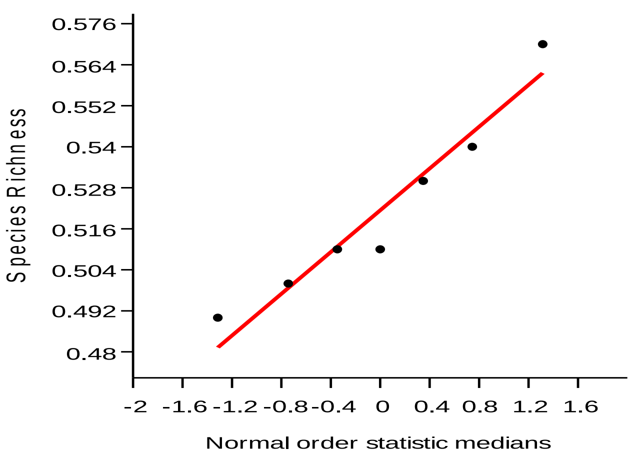

Figure 6. Dispersal species of *A. ferox* through NPC.

have potential for better performance in these sites (habitats) in the region and can be used for mass propagation/cultivation.

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Notes

HR21, Calculation of different aspects of diversity is related to threat assessment of the selected species.
HR22, Phytographs are used to define the exact phytosocilogical structure of the species in natural habitat by graphical representation.
HR23, ± means standard deviation (Sd)
HR24, Total Basal Cover
HR25, Density- Density is a measurement of population per unit area or unit volume.
Abundance, The relative representation of a species in a community
HR27, Sample size is 1X1 meter mentioned in vegetation and sampling in material and method section.
HR30 &HR31, p-value is given in the text as $p < 0.001$.

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Full Length Research Paper

Impact of climate change in Bangladesh: Role of two governments

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Bangladesh is a very low energy consuming country; it is pursuing a low carbon growth path, while building its resilience to climate change, and reducing the risk of climate change, which represents national development. Bangladesh is one of the top 10 nations; mostly vulnerable to climate change and by the end of the century, Bangladesh is set to disappear under the waves. Both Bangladesh and India are parties to the convention that obliges them to maintain natural water flow in river catchment areas to conserve regional ecology and biodiversity. There are many Transboundary Rivers and ecological issues between Bangladesh and India that needs to be resolved. India, being the neighboring country, will also be affected, if the ecology and economy of Bangladesh collapses under the weight of climate and environmental crises. It is therefore in the interest of both India and Bangladesh to work together in directions that will enable Bangladesh to withstand the climate and economic challenges that it faces. Bangladesh and India should take into consideration during their discussions and reach ecology-friendly, win-win solutions, which are common ecological issues. Both the nations should be united in the campaign for protection of the nature, ecology, and environment.

Key words: Poverty, population, migration, government's integrity.

INTRODUCTION

Massive level of human tragedies and public health threats from climate in recent years have created global awareness that climate change response and adaptation strategies are critical for national and international socio-economic, health and security. There are vital needs for sharing of strategies and technique to assist humans adapt to new conditions, while reducing their impact on earth, and to predict and prepare for climate change related crises. It also widely recognized that managing and reducing the risks associated with climate change will require inputs from all sectors of government and civil society, collaboration between many academic disciplines, and now ways of international cooperation that have hitherto eluded us. In this context, transforming research findings and lessons learnt into knowledge of adaptations planning and policy development that can be shared with the global community are crucial and timely (Griffith University, 2012).

Climate change is the biggest global health threat of the 21st century and increasingly recognized as a public health priority (WHO, 2008; Lancet, 2011, Young et al., 2002; Yongyut et al., 2009). Human induced climate change threatens ecosystems and human health on a global scale (IUCH, 2010). Climate change will have its greatest impact on those countries, which are already the poorest in the world, and it will deepen inequities, and the effects of global warning will shape the future of health among all peoples. Nevertheless this message has failed to communicate most public discussion about the climate change (The Lancet, 2011). During this century, earth's average surface temperature rises are likely to surpass the safe threshold of 2°C above preindustrial average

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temperature. Temperature rise will be greater at higher latitudes, with medium-risk scenarios predicting 2 to 3°C rise by 2090, and 4 to 5°C rise in Northern Canada, Greenland, and Siberia (Costello, et al., 2011). An update on the Intergovernmental Panel on Climate Change (IPCC's) fourth assessment identified that if there is no action to cut emissions, there is a potential for a temperature rise as much as 7°C by 2100. The fourth assessment report of the IPCC in 2007 also concluded that it was "unequivocal" that the Earth is warming and that human activities play a role in this change (New Nation, 2011a).

Climate change is taking a toll on not only the ecology of nations around the world, but also their political, economic and social stability, with the poorest nations and the poorest of the rich nations being the worst sufferers (Daily Star, 201o). A one meter rise in sea level could, for instance, flood seventeen per cent of Bangladesh's land area; threaten large parts of coastal cities such as Lagos, Cape Town and elsewhere and overwhelm, along with storm surges; small Island developing States from the Maldives to Tuvalu. A World Bank study has estimated that a one-meter sea-level rise would affect 84 developing countries alone. Recent studies have found that up to twelve per cent of the world gross domestic product (GDP) is already at risk from existing climate patterns. For example, the value of GDP exposed to tropical cyclones alone more than tripled from US$525.7 billion in the 1970s to US$1.6 trillion in the first decade of the 2000s (New Nation, 2011a).

The Global Sustainability Panel, recently set up by UN Secretary General Ban Ki-moon, is an attempt to bring a holistic approach to bear on issues, such as climate change, food, and water security, and development. However, it is has been felt that sufficient experience is lacking with how to connect dots, how to bring together concepts like climate change, and poverty eradication, climate change, and food security, and climate change, and access to water. Ultimately, if climate change is not being solved, then poverty eradication, food security, access to water cannot be solved either (Global Change, 2011). Secretary-General of UN, Ban Ki-moon affirmed that climate change was an "unholy brew" that could create perilous security vacuums, and that we must address a clear danger that not only exacerbated the threats but was itself a threat to international peace and security (Daily Star, 2011k).

Current situation

Firstly, there is a massive gap in information, an astonishing lack of knowledge about how we should respond to the negative health effects of climate change. Secondly, since the effects of climate change will hit the poor hardest, an immense task before us to address the inadequacies of health systems to protect people in countries most at risk. Thirdly, technologies do have the potential to help us adapt to changes in climate. But these technologies have to be developed out of greater research investments into climate change science, better understanding about how to deliver those technologies in the field and more complete appreciation of the social and cultural dimension into, which those technologies might be implanted. Fourthly challenge is political creating the conditions for low carbon living. And finally there is the question of how we adapt our intuitions to make climate change the priority it needs to be (The Lancet, 2011).

International cooperation is essential to face the challenges of global warming. Various development players in Bangladesh need to aid them in communicating successfully. South Asian Association of Regional Cooperation (SAARC) is also important and could be more effective for its geopolitical relationship with surrounding countries and emerge as regional strength.

However, The Bangladeshi government is taking the problem seriously, Bangladesh government has started taking measures to dredge major rivers, increase green belts in coastal areas and fortify embankments to cope with the rising sea level (Daily Star, 2009b). Recently, environmentalists and experts called for integrating natural resource management, conservation, and climate change into national planning and budgeting to ensure sustainable development in Bangladesh. They also underscored the need for improving environmental governance alongside launching sensitisation campaign among policymakers and mass people so that best practices and success stories can be replicated and scaled up across the country (Daily Star, 2011m).

Bangladesh

Geographically, Bangladesh is located in the tropical region (FAO, 2011). Natural disaster is a common phenomenon and till today Bangladesh is facing several disasters, and climate change is the main reason behind it (Daily Star, 2011a). Bangladesh is a country with great geographical vulnerability, with 70% of the population living in regions at risk of floods and 26% in regions at risk of cyclones. Not only is Bangladesh plagued with natural disasters, its population density makes it especially vulnerable to high rates of mortality and morbidity. With regard to the effect of natural disasters in South Asia in the 1960s to 1980s, Bangladesh had fewer events than either India or Indonesia, but had the highest overall mortality (Cash, 2013).

Bangladesh lies on a deltaic plain with five major river systems: the Jamuna-Brahmaputra; the Padma-Ganges; the Surma-Meghna; the Padma-Meghna; and the Karnaphuli. Although altitudes up to 105 m above sea level occur in the northern part of the plain, most elevations are less than 10 m above sea level; elevations decrease in the coastal south, where the terrain is generally at sea level. These geographical features make Bangladesh vulnerable to natural disasters, such as floods and cyclones, and the high levels of poverty increase the enormity of the challenges that the country is likely to face from climate change (ICDDR,B, 2011a) (Figure 1).

Population

The country's population now stands at 16 crore (Daily Star, 2011j), which is 1.8 crore more than a decade ago-leave behind almost unimaginable ecological footprints. Bangladesh is the third most populated country in South-East Asia after India and Pakistan, which have 121.45 crore and 18.48 crore people, according to United Nations Population Fund. Its population now is higher than the combined total of Thailand, Myanmar, Sri Lanka and Singapore.

METHODOLOGY

Information was retrieved from documents available mainly in electronic database, and on the websites of specialized agencies, using the terms 'Climate Change', and 'Bangladesh' with other researchers work was undertaken, including four leading Bangladesh daily newspapers also analyzed. Thirty five (35) documents were retrieved from the database (websites) of several national, and international agencies were browsed. The most important being online collection from different journals on climate change related issues. These sites housed a number of reports on quantitative and qualitative studies, estimates of climate change cases, policy analysis of the existing climate change-situation and reducing the vulnerability due to climate change in Bangladesh and government strategies as well as role of neighboring countries, such as India.

This paper also looked deeper at the sectoral issues and policy. The paper tried to contribute to the existing literature, in the form of new findings and in the form of critical interpretation of existing ones**.** Histological observations were carried out and a cross-sectional prevalence study of climate change and Bangladesh was also held. A scrutiny of the abstract revealed that some presentation posted on the websites, which was presented in international conferences and few other presentations were published in journals. Collected documents were skim read to cases, whether they contained information on Bangladesh in conjunction with climate change.

RESULTS

Dealing with climate change

More than 259 extreme natural events hit Bangladesh during the period 1991 to 2009. More than 80% of the deaths occurred in 1991 in Bangladesh. In 1991, a total of 140,000 people died in Bangladesh and the number significantly fall in next year's, which can be seen as partial evidence, which is possible to better prepare for climate threat and prevent larger scale impacts from catastrophe (Daily Star, 2010a). Since 1970, according to a statistics, about 39 million people have been displaced by major natural calamities like flood and cyclone in the country till 2009. Experts warn that about 6 to 8 million more people of Bangladesh could be displaced due to increase in global temperature and sea-level rise by 2050 (Daily Star, 2011).

Bangladesh is one of the top 10 nations mostly vulnerable to climate change, said German watch Global Climate Risk Index (CRI)-2011 report. By the end of the century, Bangladesh is set to disappear under the waves as mentioned by US government's NASA space agency. The International Panel on Climate Change (IPCC) predicted that by 2050, Bangladesh is on course to lose 17% of its land and 30% of its food production and as a result poverty will increase (Planetizen, 2008; The Independent, 2008). The country has already begun to feel the effects of the climate change as flood periods have become longer and the cyclones, droughts and earth quakes that hit the country cause greater devastation and adversely affecting the country's agriculture and land, and challenging water resources, occupational dislocations, food, health, energy and urban planning (Chimalaya, 2011).

The Healthy Center for Climate Prediction and Research (HCCPR) estimates that sea level in Bangladesh will rise about 40 cm (15 inches) by 2080 (Streatfield, 2008).Water level rises by at least 5.6 mm a year at *Hiron* point, 1.4 mm at Cox's Bazar and 2.9 mm at Khepupara, which was citied 2008 data from Bangladesh Water Development Board (ANN, 2010). The climate models suggest that temperature will increase in Bangladesh during all seasons by approximately 1.0 to 15°C by 2030 (Kafiluddin, 2005). The Prime Minister of Bangladesh referred to the more extreme estimations that a 1 m rise in the sea level would submerge a quarter of Bangladesh's land mass (News Today, 2011).

Disappearance of Sundarban, the Bengal tiger and birds

It was mentioned that the mangrove forests of the Sundarbans, the Bengal tiger and hundreds of bird species may disappear (Daily Star, 2011). Bangladesh and India shares important and sensitive ecological treasures, such as the mangrove forests of Sundarban and hill forests on Bangladesh's North and Eastern border.

These forests are rich in bio-diversity and they are also the areas, where members of many ethnic minorities live. It is the joint responsibility of India and Bangladesh to preserve and cherish these ecological treasures and to protect the rights of the ethnic minorities, who have been traditionally living there (New Age, 2011c)

Decreasing flow of water through the rivers from upstream is destroying the ecosystem of Sundarban. Experts from home and abroad observed that alarming

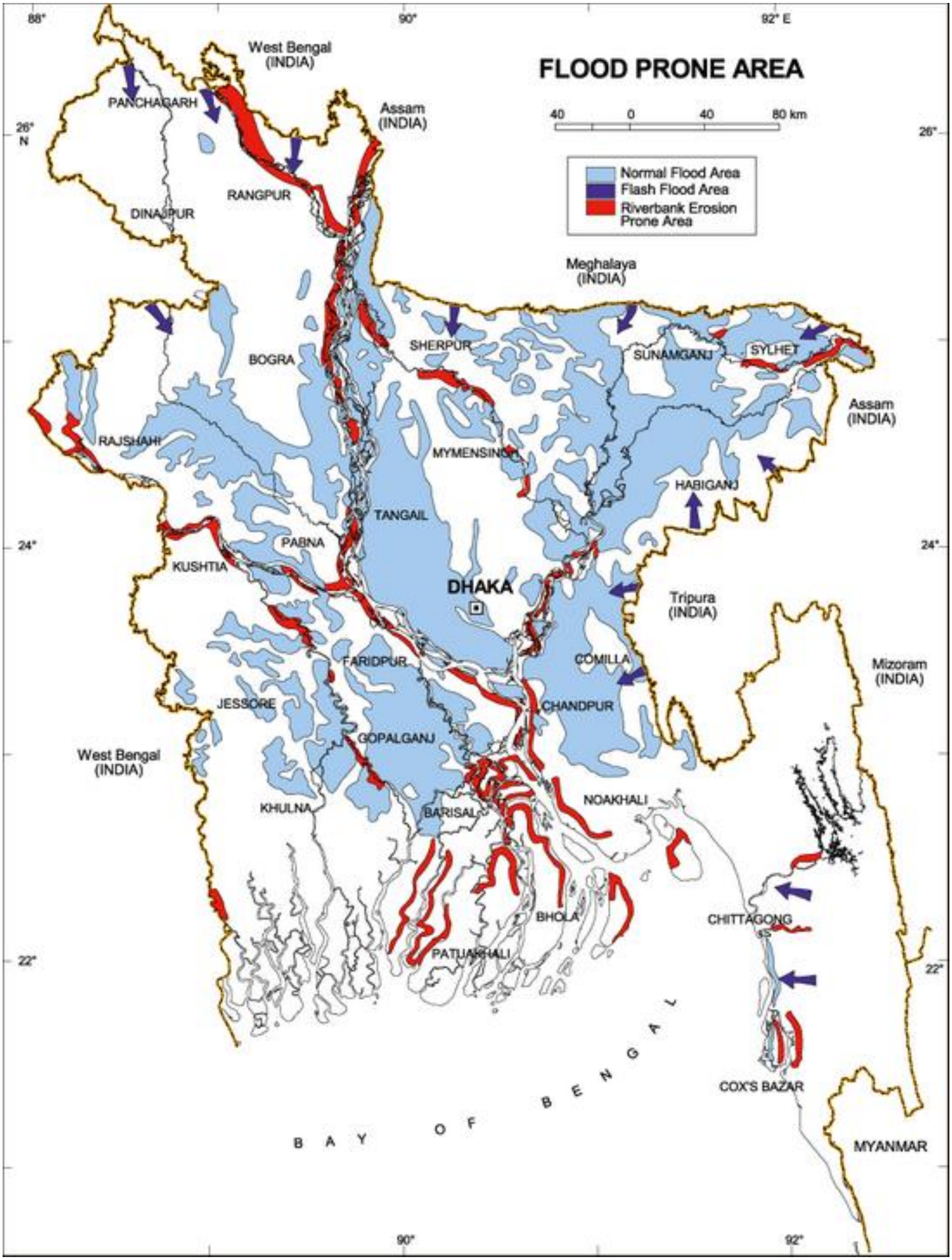

Figure 1. The above image is of areas of Bangladesh and their vulnerability to flooding. Source: http://www.banglapedia.org/httpdocs/Maps/MF_0103A.GIF

decrease in water flow down the rivers caused high salinity in both water and soil of Sundarban, causing a massive change in faunal composition of the forest. Sundarban, which lies across the outer deltas of the Ganges, Brahmaputra and Meghna rivers, is the largest mangrove forest in the world. The number of timber producing big trees such as Sundari is decreasing at the proportionate rate at the increase of salinity,' Abstract from a paper on 'Biodiversity and its Conservation in Sundarban Mangrove Ecosystem' by Indian scholars Brij Gopal and Malavika Chauhan published in the Aquatic Science journal also revealed the same result. (New Age, 2011d)

The latest report of World Conservation Monitoring warned that a long-term ecological change is taking place in Sundarban due to the eastward migration of the Ganges, abandonment of some distributaries and past diversion of water and withdrawals for irrigation (New Age, 2011d).

Changes on sea level rise

In the 21st century, climate change is expected to increase the risk of more recurrent and severe floods through higher river flows, resulting from heavier and more unpredictable rainfall in the Ganges-Brahmaputra-Meghna system during the monsoon and increased melting of the Himalayan glaciers. Its physiography and river morphology also contribute to recurring disasters. International Federation of the Red Cross and Red Crescent Societies in 2000 identified river erosion as the largest concern for Bangladesh (New Age, 2011e).

Extensive scientific research reveals that the earths freshwater is among the first and most depleted resources impacted by climate change. The IPCC (2007), reports that groundwater, crop soils and many rivers are likely to become increasingly saline from higher tidal waves and storm surges as a result of climate change effects. Bangladesh's salinity intrusion threatens greater future incursion, for numerous reasons contentiously debated by scientists. These include reduced freshwater flows into the *Padma* River caused by the Farakka Barrage; climate change induced decreases of dry season rainfall, stronger and more frequent cyclones and sea-level rise; and intensified saltwater shrimp farming (Daily Star, 2011b). The consequent salinity will affect crops and require shifts to alternative land use (Streatfield, 2008).

Migration to India

Migration taps into deep anxieties, including demographic change and increased competition over limited natural resource like water and land. India has already started to experience the impacts of climate-induced migration from Bangladesh. The likely outcome will be to split the economies of Indian and Bangladeshi Border States, with flow-on effects for places at a higher elevation, given the unpreparedness of both these countries.

It is therefore immensely important for both countries to work together to handle migration and to manage their 4,097 km long border. India also needs to be proactive in initiating the Joint Climate Change Mitigation Forum, which could help Bangladesh and its citizens with mitigation and adaptation measures. This is crucial for India, because dealing with such a massive influx of people into its own territory will be an enormous challenge (East Asia Forum, 2013).

DISCUSSION

Journalists have an important role in spreading the right message on climate change issues among others. A new advocacy and public health movement is needed urgently to bring together governments, international agencies, non-governmental organization (NGOs), communities, and academics from all disciplines to adapt to the effects of climate change on health (Costello et al., 2011).

In addition to that it is the duty of the agronomists to help the farmers at field level and guide the policy-makers to achieve the desired yield of crops (ANN, 2010a). Moreover, all types of possible anti Natural Catastrophe steps should be taken *now* by the government (Daily Star, 2010a). The recent establish 'climate change unit' under environment and forest ministry need to be made pro active. The bilateral treaty between India and Bangladesh, it did not address the issue of water diversion by India in the upstream areas (Daily star, 2011h).

Regional conferences are necessary as this can be a platform to reach a bigger audience. Referring to very little information available for the government, civil society members and experts of Bangladesh, sharing environmental/ecological data among the bordering countries is very necessary as this is a question of life and death for the people (Daily star, 2011h).

Instead of treating migration simply as a threat, and viewing it from a narrow security perspective, India should explore the possibility of collaborating with Bangladesh to address future climate-induced migration. Collaboration could take the form of a joint mechanism to deal with different kinds of migration, with a special focus on establishing combined disaster management groups to deal with climate change problems at their source. This could be accomplished by implementing innovative adaptation mechanisms in Bangladesh itself (East Asia Forum, 2013).

Conclusion

We need to create scope for joint projects (both from India and Bangladesh) on scientific research on tigers and the Sundarbans ecosystem. However, recent agreement on biodiversity says none of the two countries will do anything that may have an adverse impact on biodiversity and ecosystem, which is one of the main obligations of the Convention on Biological Diversity, 1992. Both Bangladesh and India are parties to the convention that obliges them to maintain natural water flow in river catchment areas to conserve regional ecology and biodiversity (Daily Star, 2011m).

There are many transboundary rivers and ecological issues between Bangladesh and India needs to resolve. There is no doubt that, India, being the neighboring country, will also be affected if the ecology and economy of Bangladesh collapses under the weight of climate and environmental crises. It is therefore in the interest of both India and Bangladesh to work together in directions that will enable Bangladesh to withstand the climate and economic challenges that it faces. Bangladesh and India should take into consideration during their discussions and reach ecology-friendly, win-win solutions. Common ecological issues, such as 1) Farakka Barrage on the Ganges 2) Indian barrages on the River Teesta 3) *Tipaimukh* Dam on the River Barak 4) Interventions into the River Brahmaputra e) Indian river linking project 5) Cross border flush floods 6) Cross border pollution 7) Approaches to the rivers (New Age, 2011c)

It is imperative that India seeks to address the issue of migration from Bangladesh, by joining hands with the latter and ensuring economic development of the latter and not through knee jerk reactions like sealing the borders (East Asia Forum, 2013).

Bangladesh government should ensure proper water sharing with India. An integrated water management and development project on the Ganges, Brahmaputra and Meghna should be taken to resolve the water catastrophe of Bangladesh (New Age, 2011c). Former caretaker advisor believes that the government should press for the formation of a Teesta River Commission a la the Mekong River Commission (in Southeast Asia) for total basis management in light of the framework agreement. Advisor believes that when there will be a climate of goodwill in both sides, only than people will build connectivity for them across the region (New Age, 2011f). Nation should be united in the campaign for protection of the nature, ecology, and environment.

Comments from climate change activist

Secretary General, Ban ki Moon warned the world leaders that Climate Change was '***to mobilize the political will and vision needed to reach an ambitious agreed outcome based on science** at the UN climate talks in Copenhagen… there is little time left. The opportunity and responsibility to avoid catastrophic climate change is in your hands'* (New Age, 2011a).

"*Globally, we are talking about the largest mass migration in human history*," says Maj. Gen. (R) Muniruzzaman."*By 2050 millions of displaced people will overwhelm not just our limited land and resources but our government, our institutions, and our borders*" (Envoinfo, 2010).

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Visible near infra-red (VisNIR) spectroscopy for predicting soil organic carbon in Ethiopia

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Over the past few decades, the advantages of the visible-near infra-red (VisNIR) diffuse reflectance spectrometer (DRS) method have enabled prediction of soil organic carbon (SOC). In this study, SOC was predicted using regression models for samples taken from three sites (Gununo, Maybar and Anjeni) in Ethiopia. SOC was characterized in laboratory using conventional wet chemistry and VisNIR-DRS methods. Principal component analysis (PCA), principal component regression (PCR) and partial least square regression (PLS) models were developed using Unscrambler X 10.2. PCA results show that the first two components accounted for a minimum of 96% variation which increased for individual sites and with data treatments. Correlation (r), coefficient of determination (R^2) and residual prediction deviation (RPD) were used to rate four models built. PLS model (r, R^2, RPD) values for Anjeni were 0.9, 0.9 and 3.6; for Gununo values 0.6, 0.3 and 1.2; for Maybar values 0.6, 0.3 and 0.9, and for the three sites values 0.7, 0.6 and 1.5, respectively. PCR model values (r, R^2, RPD) for Anjeni were 0.9, 0.8 and 2.7; for Gununo values 0.5, 0.3 and 1; for Maybar values 0.5, 0.1 and 0.7, and for the three sites values 0.7, 0.5 and 1.2, respectively. Comparison and testing of models shows superior performance of PLS to PCR. Models were rated as very poor (Maybar), poor (Gununo and three sites) and excellent (Anjeni). A robust model, Anjeni, is recommended for prediction of SOC in Ethiopia.

Key words: Prediction, soil organic carbon, visible near infra-red, spectrometer, Ethiopia.

INTRODUCTION

Concerns about global warming have resulted in an international agreement on reducing the emission of greenhouse gases (Kandel et al., 2011). The concern created a renewed interest in determination of soil organic carbon (SOC) content (Brunet et al., 2007). SOC represents one of the major pools in the global C cycle. Therefore, small changes in SOC stocks cause an important CO_2 fluxes between terrestrial ecosystems and the atmosphere (Stevens et al., 2006). Determination of SOC content is an important part of research to examine the fluxes.Current technologies to determine SOC depend on two categories of technologies often described as “intensive” and “non-intensive” (McCarty et al., 2002).

To quantify SOC, “intensive technology”, uses several different techniques of fractionation and chemical extractions procedures. The intensive technologies include dry combustion for total carbon, calcimeter method for inorganic carbon and wet oxidation for SOC (Janik et al., 1998; Sankey et al., 2008; Walkley and Black, 1934). “Intensive technologies” are conventional and standard procedures but are time-consuming, laborious and expensive. The existence of several deviations in analytical

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Abbreviations: SOC, Soil organic carbon; **VisNIR,** visible near infra-red; **DRS**, diffuse reflectance spectrometer; **NIRS**, near infra-red spectrometer; **GUN**, Gununo; **ANJ**, Anjeni; **MAY**, Maybar; **3 SITES,** all sites.

procedures among the standard methods makes them more complex (McCarty et al., 2010).

In recent years, the "non-intensive technology" method is used as an alternative method because of its multiple advantages. Attention is given for such an alternative method as Visible near infrared reflectance (VisNIR) using diffuse reflectance spectroscopy (DRS) (Brunet et al., 2007). VisNIR-DRS methods are new, rapid, simple, non-destructive, reproducible, cost effective and some times more accurate than conventional analytical methods (Chang et al., 2001; Brown et al., 2005; Gomez et al., 2008; Cecillon et al., 2009; McCarty et al., 2010).

It is well-known fact that infrared predicted data can never be better than the original laboratory values. VisNIR-DRS method is less accurate than conventional laboratory methods such as wet oxidation and dry combustion (Stevens et al., 2006). If the sources of laboratory error can be identified, however; the VisNIR method may in fact be a better tool for interpretation than the 'appropriate' chemical analysis (Janik et al., 1998). A comprehensive review on advantages and disadvantages of VisNIR Spectrometer exist in Blanco and Villarroya (2002). VisNIR Spectrometer methods have also a limitation associated with instrumentation, data transferability, variation in study scale (Mouazen et al., 2010). In spite of these limitations, progress has shown the potential of Visible-Near Infra-Red Reflectance (VisNIR) for soil analysis (Janik et al., 1998).

In predicting SOC various types of spectrometers (DRS) are used (Blanco and Villarroya, 2002). The most common types of spectrometers are described as diffuse reflectance (DR), Mid Infrared (MIR) and Near Infrared (VisNIR). In this study, VisNIR spectrometer was used with range from 700 to 2,500 nm wavelength (Viscarra Rossel et al., 2006; Viscarra Rossel and McBratney, 2008). DRS has been used in soil science research since the 1950s (Viscarra Rossel and McBratney, 2008), however, characterizing soil using VisNIR-DRS dates back to the 1960s (Brown et al., 2005). Over the past 40 years, VisNIR-DRS methods have been developed as tool to predict SOC (Kang, 2006). Today the wide application of VisNIR-DRS methods has resulted in a modern technique for landscape modeling (Brown et al., 2005) precision agriculture (He and Song, 2006; Brown et al., 2005) digital soil mapping (Viscarra Rossel and McBratney, 2008) and soil C monitoring (Brown et al., 2005; Ge et al, 2011) for use in carbon sequestration studies and carbon finance.

VisNIR-DRS method involves analytical correlation of spectral data for predicting soil physical and chemical properties (He and Song, 2006; Chang et al., 2001; Genot et al., 2011) including SOC (Brown et al., 2005; Brown et al., 2005; Kang, 2006; Reeves et al., 2006; Gomez et al., 2008; Ge et al., 2011). The method has been reported as an accurate way of predicting SOC in laboratory (Gomez et al., 2008; McCarty et al., 2002; Stevens et al., 2006). Existing challenges limiting use of VisNIR-DRS includes finding suitable data treatment and calibration strategies (Chang et al., 2001). As soil organic matter is complex, spectra results are not directly informative (Brunet et al., 2007). There is complexity of spectra and overlapping bands associated with its soil organic matter component (Kang, 2006; Sankey et al., *2008*). The VisNIR spectra for SOC have not been well described so far, perhaps due to the complexity of material (Brown et al., 2005). Moreover, soil constituents various materials other than organic matter, which interact in a complex way to produce a given spectrum. So, direct quantitative prediction of soil characteristics is impossible (Cecillon et al., 2009; Chang et al., 2001). It is good to note that soils are more diverse in composition compared with traditional VisNIR products like grains or forages (Ge et al., 2011). It is therefore rather possible to calibrate model to predict soil organic carbon.

Simple equations involving pedo-transfer functions are used for predicting soil properties (Janik et al., 1998). Likewise, over the past decades, both physical and chemical properties of soils have been predicted from soils spectral data using multivariate equations (Kang, 2006; Cecillon et al., 2009). The prediction is successful for soil organic carbon. Multivariate analysis is used to construct models capable of accurately predicting properties of unknown samples. Multivariate calibration methods such as multiple linear-regression (MLR), principal components regression (PCR), Boosted Regression Trees (BRT), Artificial Neutral Networks (ANN), Locally Weighted Regression (LWR) and partial least squares regression (PLSR) has been applied to all spectroscopic studies (quantitative analysis) with variable degrees of success (Kang, 2006; Chang et al., 2001; Genot et al.,2011). PLS, PCR, MLR are good where there is linear relationship while ANN and others can be used where there is no linear relationship (Blanco and Villarroya, 2002). None of the above models are universally accepted and there are variously proposed calibration techniques (Chang et al., 2001; Genot et al., 2011).

Regression techniques involve relating the soil spectral data measured using VisNIR-DRS to laboratory measured soil properties (Ge et al., 2011). In this study, spectral data was related with SOC determined using analytical (Walkley and Black) method using multivariate regression models. Models built are tested using full prediction method and checked for accuracy using statistical parameters (Chang et al., 2001; Kandel et al., 2011).

This study makes use of three models: PCA, PLS and PCR. These models were selected for three reasons. First, they are full spectrum data compression techniques (Viscarra Rossel and McBratney, 2008; Naes et al., 2002). Second, the models can handle co-linearity. Third, they are most widely used and successful in SOC predictions (Blanco and Villarroya, 2002; Ge et al., 2011). As reviewed by Stevens et al. (2006), PLS and PCR are more frequently used than other models. MLR model was not used in this study because of its limitation in leverage correction and handling co-linearity (Stevens et al., 2006; CAMO, 2012).

As reviewed by Brown et al. (2005), soil properties were predicted using VisNIR Spectrometer in a wide range of scale representing soil variability from local, regional to global libraries. Regional libraries refer to a greater geographic extent than local libraries while global libraries are based on major soil taxa from multiple continents (Sankey et al., 2008; Brown et al., 2005). A comparison of results by Sankey et al. (2008) and review by Chang et al., (2001) and Stevens et al., (2006) shows that local libraries have better calibration accuracy compared with regional and global libraries. This study attempts to build four models (for individual 3 sites and all three sites) and recommends the most robust model for prediction of SOC in Ethiopia. Until recently, VisNIR-DRS has not been used as a tool to predict soil properties in Ethiopia. The paper specifically attempts to show the effect of data treatment on models, model testing and selection.

MATERIALS AND METHODS

The study area

The study areas are located in the Ethio-Swiss Soil Conservation Program (SCRP) sites established in 1980s. The sites are Gununo in South, Maybar in North-Eastern and Anjeni in North-Western Ethiopia. Gununo site is situated in Wolayita Zone, at 16 km WNW of Sodo town at 37° 38' E /6° 56 'N (SCRP, 2000, b) in Damote-Sore district. Maybar site is situated in South Wello Zone, 14 km SSE of Desse town at 39° 40' E /11 00 'N (SCRP, 2000d) in Albulko district. Anjeni site is situated in West Gojam Zone,Dembecha district at 15 Km North of Demecha at 37° 31' E /10° 40 'N(SCRP, 2000c) (Figure 1).

Methods

An equivalent mass depth soil sampling method was used as suggested for soil carbon study by Stolbovoy et al. (2002). Soil samples were taken from 64 soil profiles in three sites. Although the study sites are small in size, there are different types of soil types in the areas (Table 1) resulted in an intensive sampling. Depending on profile depth, samples were taken from 0-10, 10-30, 30-50, 50-100 cm depths. Although SOC distribution decrease with soil depth, its concenteration is visible up to 1 meter (Allen et al., 2010). Thus, deep sampling protocol is suggested for SOC study (Baker et al., 2007). Total soil samples are 96 from Gununo, 98 from Anjeni and 81 from Maybar. As recommended by Brunet et al. (2007) and Knadel et al. (2011) soil samples were grinded and sieved through 0.2 mm for better carbon prediction as used in this study.

A field spectroscopy (VisNIR-DRS) by Analytical Spectral Device (ASD) Incorporation was used for measurement of 275 samples taken from three sites. SOC was measured in laboratory using standard procedure for wet oxidation method as described in Walkley and Black (1934). Scanning procedures are as described in Brown et al. (2005) with detail protocols as indicated in Viscarra Rossel (2009). Reflectance spectra were measured on petri dishes, twice for each sample using a mug light. Spectra wavelength ranges from 350 to 2500 nm. Data reduction methods are needed in VisNIR Spectrometer study (Blanco and Villarroya, 2002). Following spectra data transposing for pre-processing, data was reduced using average (for replicate sample spectra measurement). Then every 10^{th} of the wavelength was selected.

There also seems to be lack of clarity on pre-processing to optimize spectral data (Brunet et al., 2007). Proper data pre-treatment help develop accurate calibration (Reeves et al., 2006; Blanco and Villarroya, 2002). Having tested various data pre-treatment procedures, Multiplicative scatter correction (MSC) and Detrending (DT) were selected to get best calibration and validation result. Steps used in developing multivariate models are as described in Blanco and Villarroya (2002) and CAMO (2012).

Unscrambler X 10.2 (CAMO Software, Analytical Spectral Device {ASD}, Oslo, Norway) (CAMO, 2012) was used for data pre-treatment, model calibration, validation and testing. Using test set validation method; principal component analysis (PCA) was used to examine hidden structure of data, to visualize relationship (similarity and difference) between soil samples and spectral wavelength (variables). PCA was used mainly to describe sample effect on models. PCA was used as descriptive tool while PCR and PLS were used as predictive tool. SOC content was regressed against soil spectra using PLS and PCR.

All model calibration involves selecting 10 components (factors), testing regression coefficients at *$P < 0.05$% significance level with test set validation. A total of 4 models were built for three individual sites independently and for all the three sites (altogether). To develop model for the three sites, data (n=275) was divided in to validation (30%, n=82) and calibration (70%, n=193) set. In developing each site models, validation and calibration samples are 28 and 68 for Gununo, 29 and 69 for Anjeni and 24 and 57 for Maybar, respectively.

The regression models were compared to examine accuracy and predictive ability using correlation coefficient (r), slope, coefficient of determination (R^2), root mean error of calibration (RMEC) and prediction (RMEP). Ratings of the models in this study were based on combining two parameters. The first parameter was based on R^2 values rate as suggested by Viscarra Rossel and McBratney (2008). The second parameter was based on RPD value rate as suggested by Mouazen et al. (2010). The accuracy of developed models were tested using full prediction by examining (predicted and reference plot) which shows the difference between measured and predicted values.

RESULTS AND DISCUSSION

Soil organic carbon (SOC) analytic result

The soil of the study sites were described and classified by the Ethio-Swiss Soil Conservation Program (SCRP) (Kejela, 1995; Weigel, 1986,a, Weigel, 1986,b). Altitude of the study area varies from 1982 to 2858 meter above sea level (m.a.s.l). Traditional agro-ecology of the sites varies from Moist WeynaDega to Wet WeynaDega.

SOC samples of the three sites (n= 275) have 2.5 mode and 1.9(g/Kg) median. SOC data is skewed positively (0.8, standard error of skewness = 0.14) with first quartile (Q1) = 1.0 and third quartile (Q3) = 2.6 values.

Previous soil studies in the area, SOC was also determined using Walkley and Black method (though sampling procedure varies). Anjeni was described as soils with low organic carbon (Zeleke, 2000; SCRP, 2000, c). Kejela (1995) found OC variation with maximum values with Phaeozem surface layers with 4.6% and minimmum with sub soils of (Gleysol-Fluvisol) with 0.05. SOC % in Zeleke (2000) and SCRP (2000c) varied from 1.1

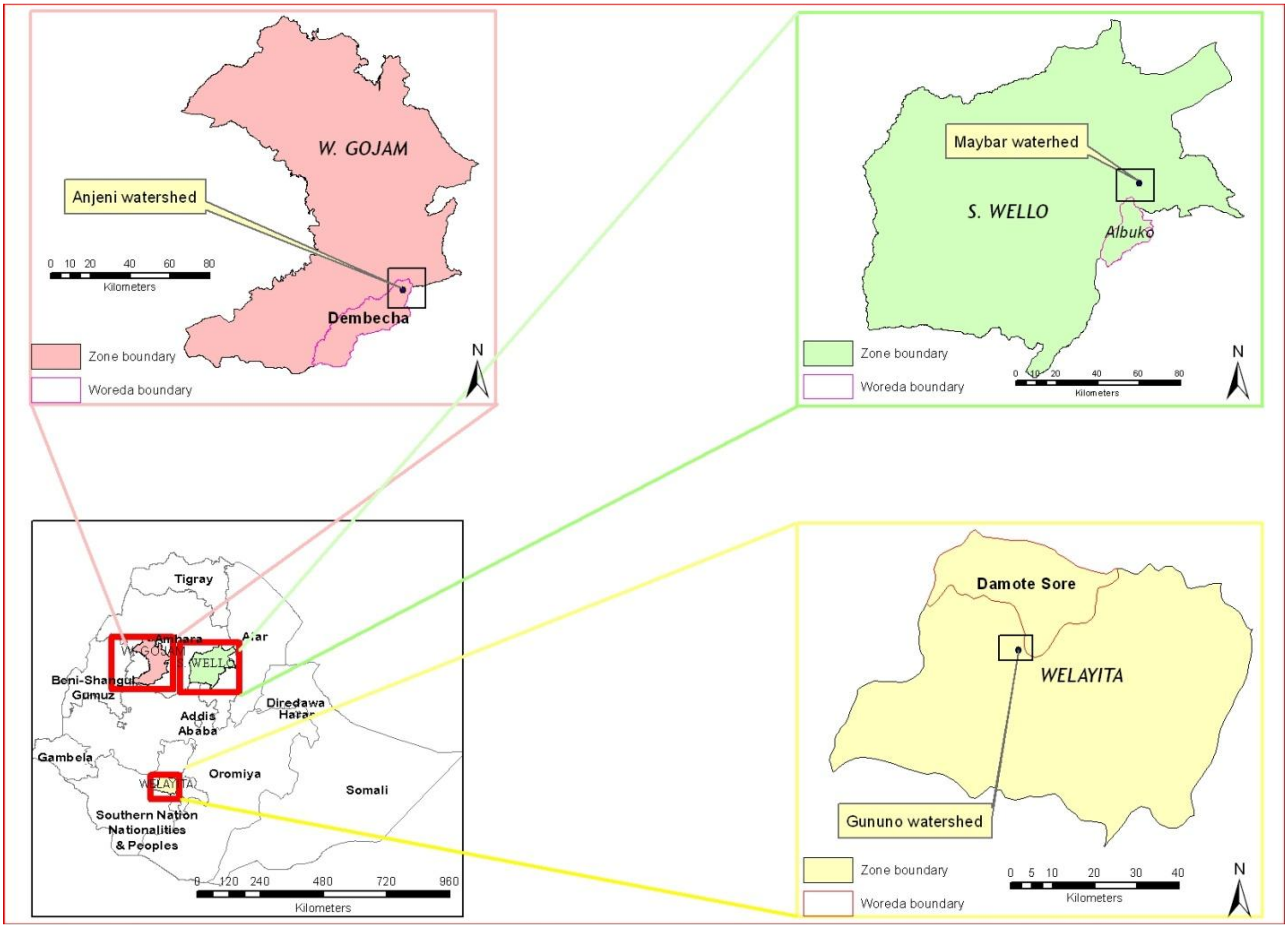


Figure 1. Location of study sites in Ethiopia.

Table 1. Description of soils of the study sites.

Name of research site	Gununo (GUN)	Maybar (MAY)	Anjeni (ANJ)
Climate (Thornthwaite classification) *±	Temperate , humid	Temperate , Sub-humid	Temperate , Sub-humid
Parent materials*,±	Trapp series of tertiary volcanic eruptions, ignimbrites,rhyolite , trachites and tuffs	Volcanic Trapp series with alkali-olivine basalts	Basaltic Trapp series of the tertiary volcanic eruption, tuff
Major soil Types (FAO-UNESCO)	Nitosols, Acrisols, Phaeozems, Fluvisols	Phaeozems , Lithosols, Gleysols	Alisols, NitosolsCambisols
Size of study area (ha)	166.8*	519.7*	918.4*

*Based on SCRP, 2000a; SCRP, 2000b; SCRP, 2000c; SCRP, 2000d; ± Kejela (1995), Weigel (1986a), Weigel (1986b).

to 3.9% mainly because survey area was smaller compared with Kejela (1995). Weigel (1986a) indicated that high percentage of OC is available in Gununo with some soil units of Humic Acrisols and Nitisols. Organic

Table 2. Soil organic carbon (SOC, g/kg)) descriptive statistics.

Site	Sample number (n)	Min	Max	Mean	Std. Deviation	Variance
***MAY** (North - West- Ethiopia)	81	0.26	6.7	2.8	1.5	2.2
***GUN** (South - Ethiopia)	96	0.20	3.3	1.8	0.8	0.7
***ANJ** (North - East Ethiopia)	98	0.05	3.7	1.4	1.1	1.0
3 sites (all sites)	275	0.05	6.7	2.0	1.2	1.6

MAY*=maybar, ANJ*=Anjeni, GUN*=Gununo.

Table 3. SOC % variation accounted by first components with raw spectra.

Raw spectra$^+$	Maximum components*	% Variation accounted by components (PC$^{\pm}$)		
		PC1	PC2	PC3
Gununo(GUN)	10	78	20	2
Anjeni(ANJ)	10	82	16	2
Maybar(MAY)	10	89	10	1
3 SITES (all)	10	71	25	3

PC$^{\pm}$= major principal component (1, 2, 3) *Optimum components = 3, $^+$No treatment.

Matter (OM) variation shows that some layers of Humic Acrisols has a maximum of 6.2% while Eutric Nitosols has a minimum of 1.2% (% OM = O.C% X 1.72).Weigel (1986, b) characterized SOC variation of Maybar with maximum values at depths of Phaeozem soil profiles with 5.9% OM and minimum value of 1.5 % OM at some depth. Comparison of variation of SOC (g/Kg) across the sites shows that the minimum values were recorded in Anjeni and higher values in Maybar (Table 2).

Principal component analysis (PCA)

PCA shows that the first two principal components accounted for a minimum of 96% of the variance (raw spectra for all the three sites). Percent variance increased for specific sites (Table 3) and with data treatment. For example, for the three sites, with De-trending the first two components accounts for 99% of the variance.

PCA is used to find out outliers in a data set (Tobler, 2011). Maybar samples have 4% potential outliers (Figure 2). Under normal situation, 5% of the samples may lie outside the ellipse (CAMO, 2012). Samples far from center have high leverage (potentially influential) (Naes et al., 2002; CAMO, 2012). If leverage values for samples are above 0.4, it is “bothering” (CAMO, 2012). Maybar sample has 9% highest and worse absolute leverage values with 4% potential outliers which have reduced model quality.

The result explains why Maybar model has least predictive ability as reflected in values of correlation (r), coefficient of determination (R^2) and residual prediction deviation (RPD) in both PLS and PCR models (Figures 3 and 4). Samples, which appear as potential outliners, were not removed in this study because they contain real soil information measured under laboratory condition. Comparison of variances showed the closeness of calibrated and validated curves, which reflected that models were true representativeness and there is absence of threat from outliers. A further data treatment with Multiplicative Scatter Correction (MSC) and De trending (DT) also developed better PCA with fewer components.

Principal component regression (PCR)

PCR is a multivariate regression analysis technique. PCR is used in predicting SOC using VisNIR-DRS. PCR and PLS provide similar results, though PLS usually converges in less factors than PCR. Although there seems to be confusion on data pre-processing to optimize spectral features for SOC prediction, Chang et al. (2001) points out that finding suitable data treatment is main challenge in VisNIR-DRS study.

Some authors prefer derivatives (Brunet et al., 2007) but in this study, results using first and second order derivatives were even worse than the raw spectral data. Various data treatment methods (moving average, baseline, standard normal variant (SNV) were tested before selecting MSC and Detrending (DT). The various data treatment procedures (baseline effect, moving average) have improved the models a little compared with raw spectral data.

Partial least square regression (PLS)

Review shows that the most frequently used regression

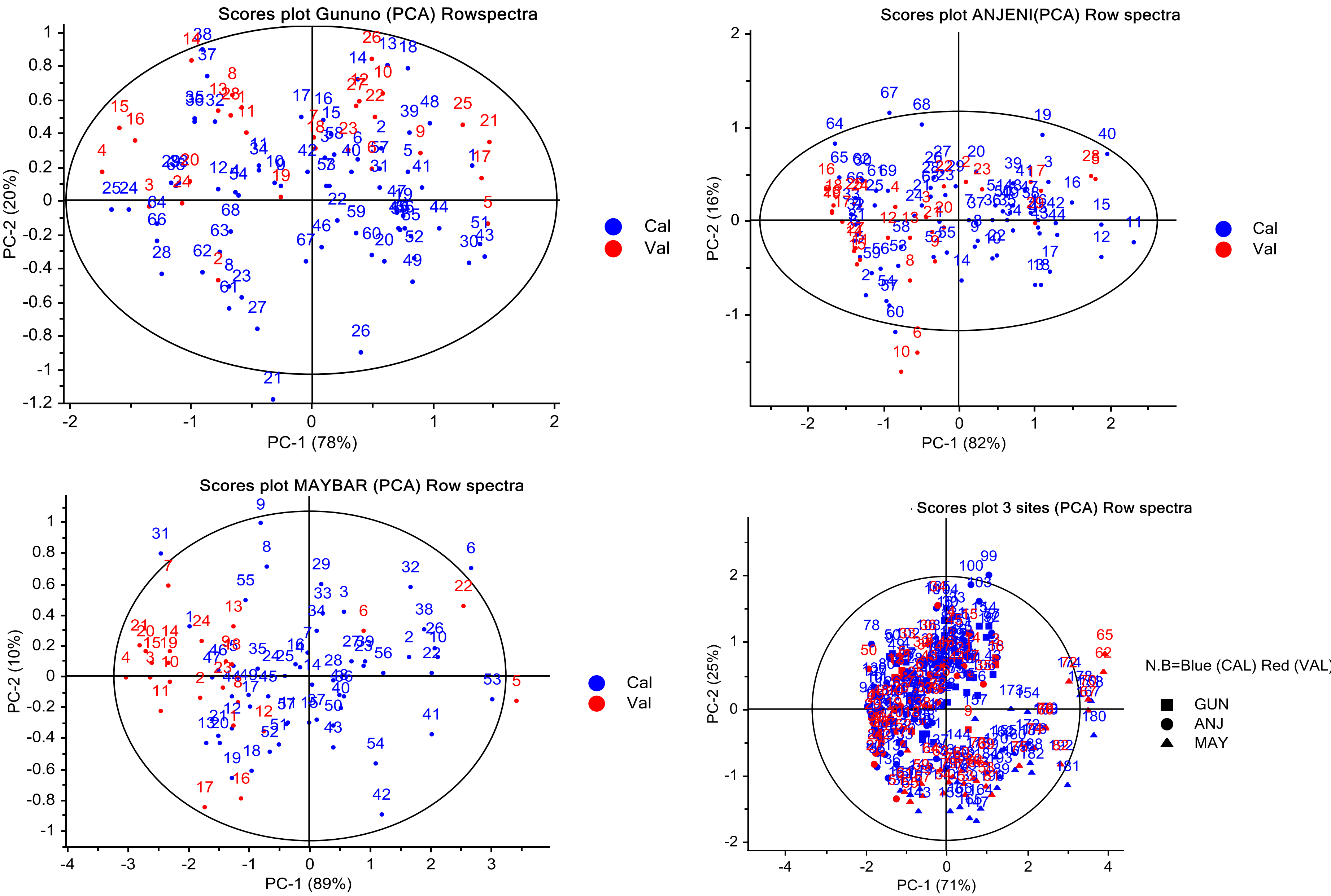


Figure 2. Score plot for first principal components (PC1, PC2) for each and 3 sites altogether.

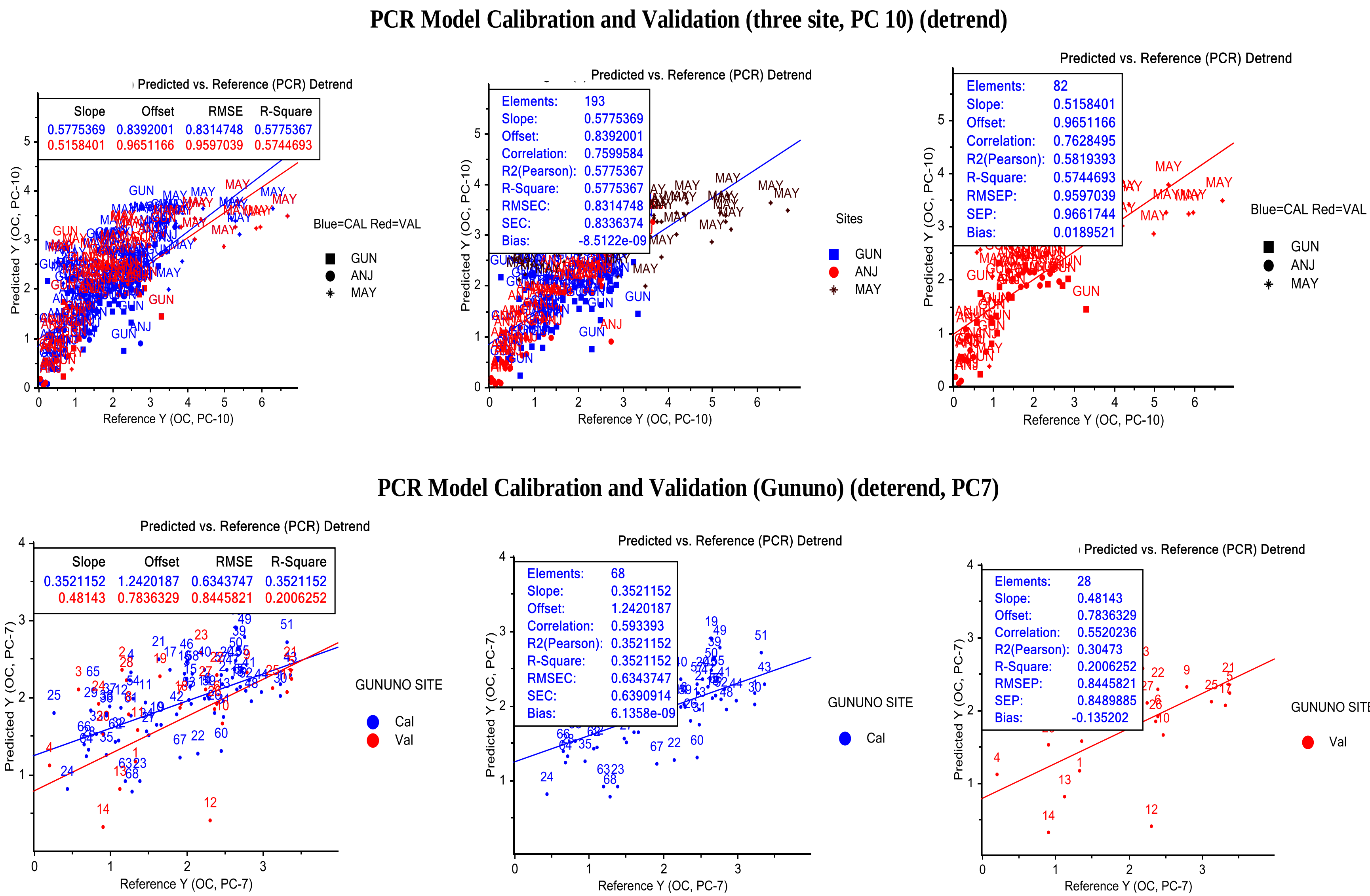
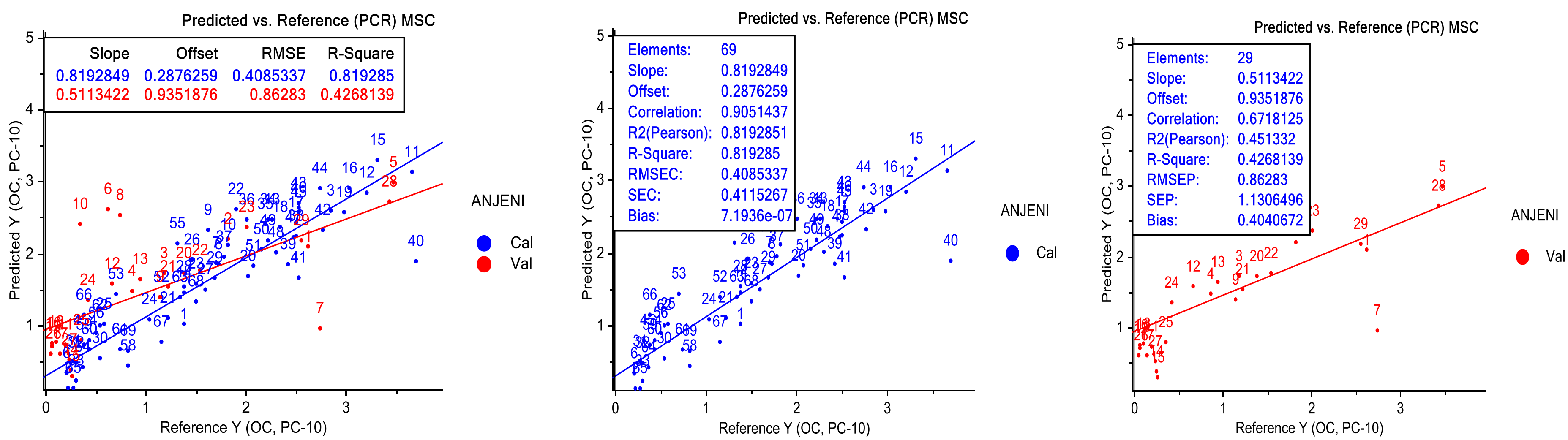


Figure 3. PCR models for individual sites and three sites altogether (validation and calibration). Offset = intercept, SEC= standard error of calibration, SEP = standard error of performance/prediction, R-Square (R^2) = coefficient of determination, Correlation (r) = correlation, RMSEP = root mean square of error of prediction, RMSEC = root mean square of error of calibration MSC = multiplicative signal correction, Deterend = De trending, PCR = principal component regression, PLS = partial least square regression, SEC = standard error of calibration SEP = standard error of performance/prediction, NB = The % SOC predicted values (y) are based on spectral measurement while the measured values (x) are measured using Walkley and Black method.

PCR Model Calibration and Validation (Anjeni) (MSC, PC10)



PCR Model Calibration and Validation (Maybar) (MSC, PC10)

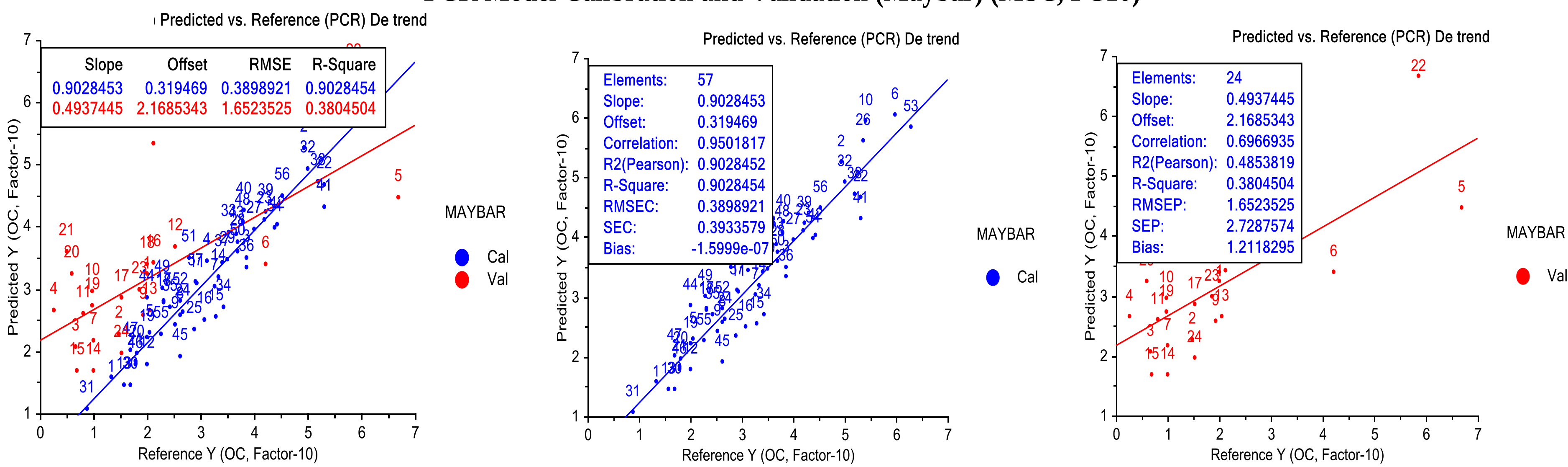


Figure 3. Contd.

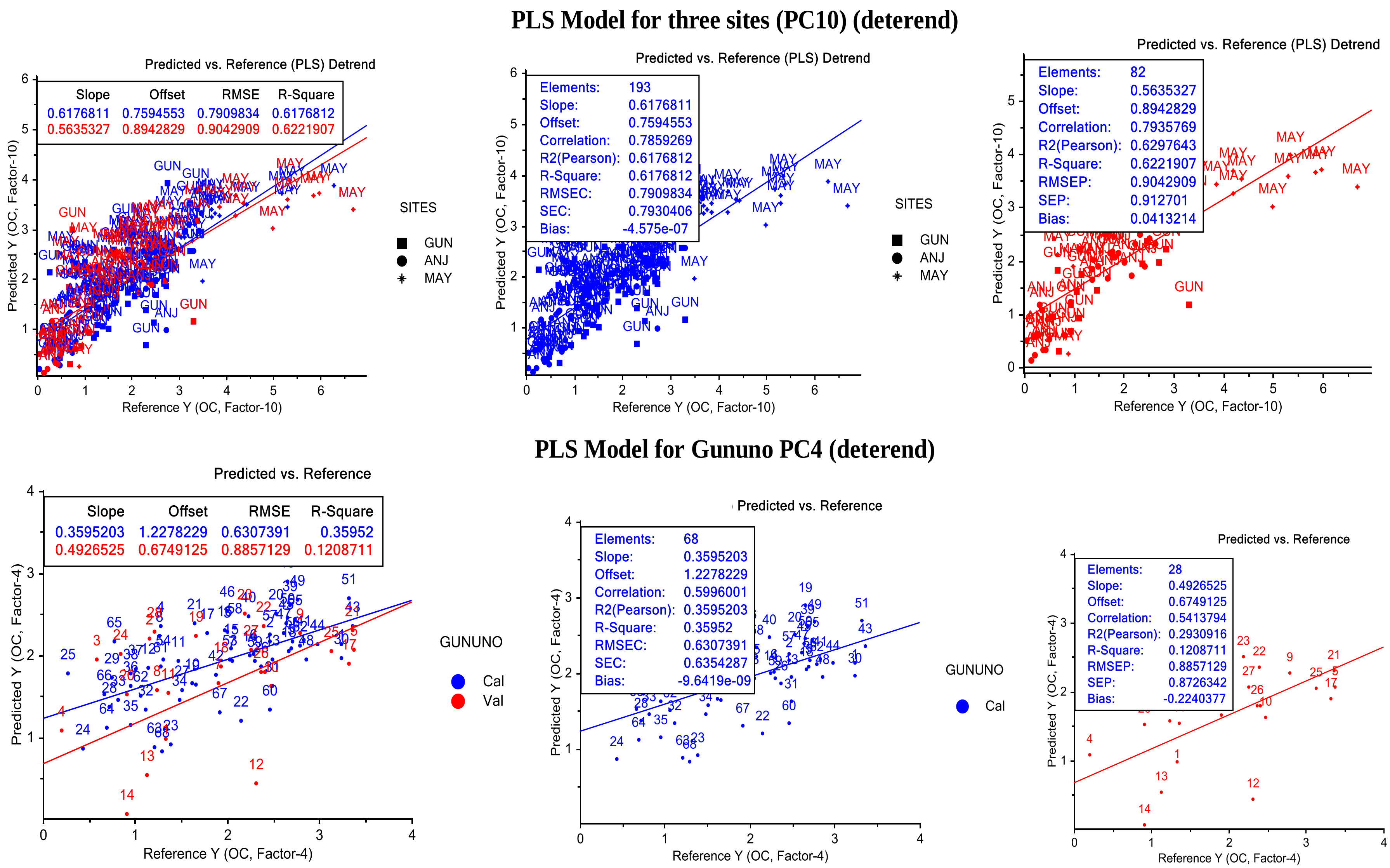
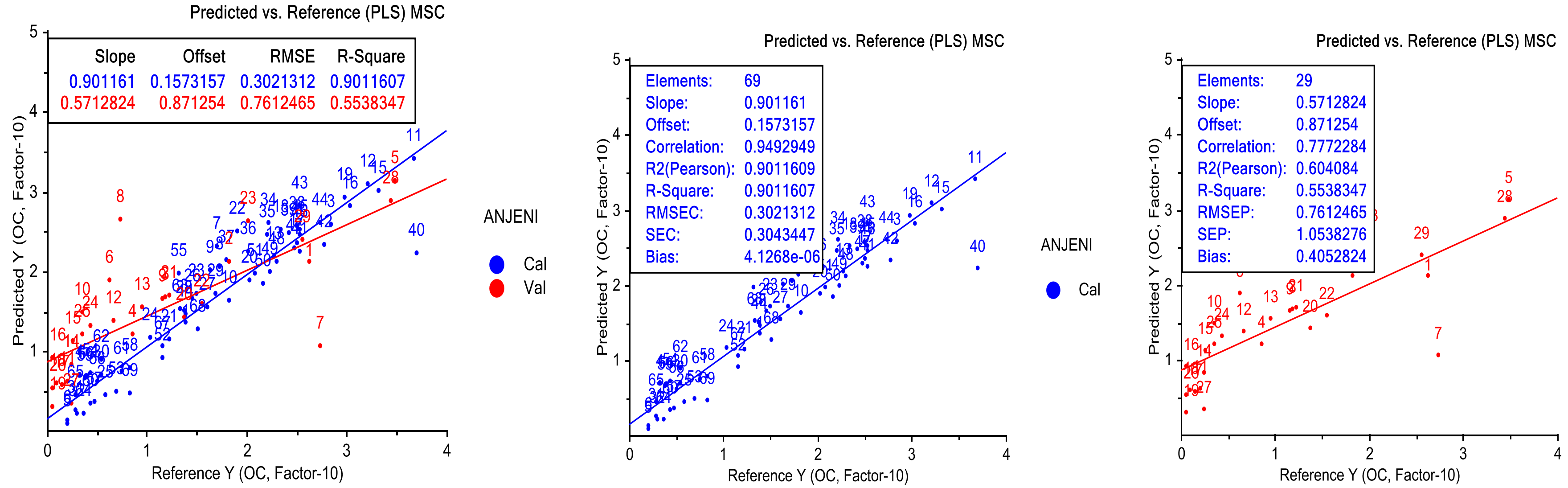


Figure 4. PLS Models for individual sites and three sites altogether (validation and calibration). Offset = intercept, SEC = standard error of calibration, SEP = standard error of performance/prediction, R-square (R^2) = coefficient of determination, correlation (r) = correlation, RMSEP = root mean square of error of prediction, RMSEC = root mean square of error of calibration MSC= multiplicative signal correction, Deterend = De trending, PCR = principal component regression, PLS = partial least square regression, SEC = standard error of calibration SEP = standard error of performance/prediction, NB = the % SOC predicted values (y) are based on spectral measurement while the measured values (x) are measured using Walkley and Black method.

PLS Model for Anjeni PC10 (MSC)



PLS Model for Maybar PC10 (deterend)

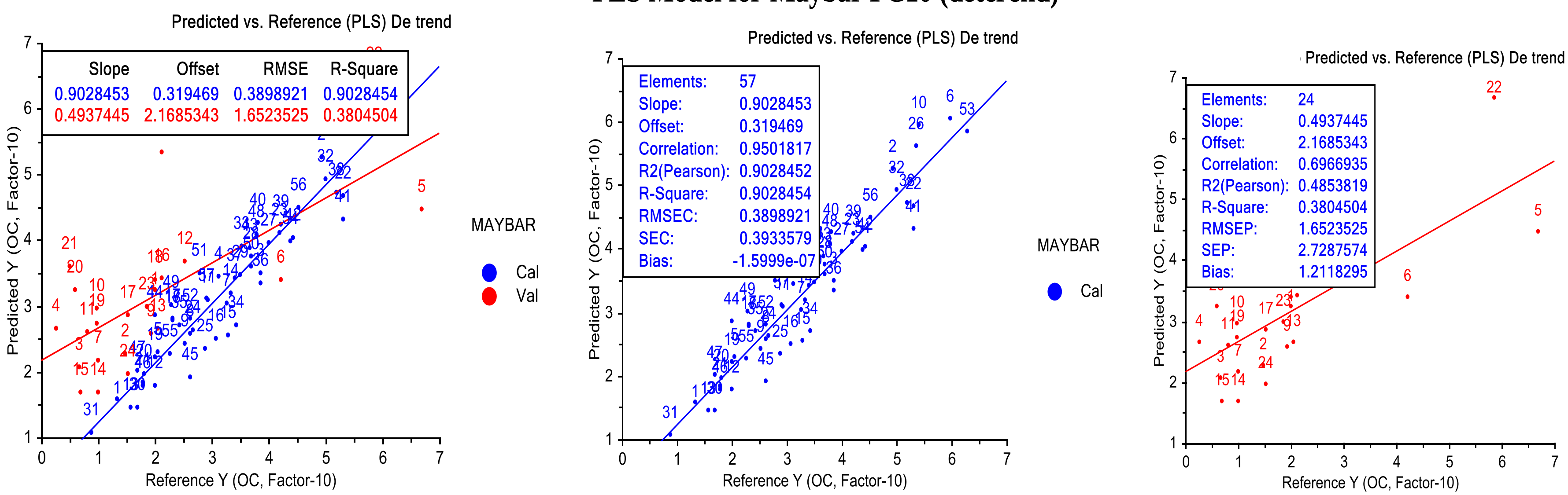


Figure 4. Contd.

Partial least square regression (PLS)

Review shows that the most frequently used regression models in VisNIR-DRS are PCR and PLS (Blanco and Villarroya, 2002; Viscarra Rossel et al., 2006). Both PCR and PLS can cope with data containing large numbers of predictor variables that are highly collinear (Viscarra Rossel and McBratney, 2008). PLS is the most preferred and popular method to predict SOC (Kang, 2006; Viscarra Rossel et al., 2006; Viscarra Rossel and McBratney, 2008). PLS is used for accurate prediction of site-specific data sets to establish local spectral library (Sankey et al., 2008). SOC measured with Walkley-Black method have been predicted from local to global spectral level using PLS in VisNIR-DRS. Review of past studies on SOC by He and Song (2006) found correlation of 0.9 for soil organic matter (n= 30) RMSEP = 0.12, RMSEC=0.058. Brown et al. (2005) predicted SOC (n= 3793) with correlation of 0.82, Slope =0.76, RMSD=0.9% (with first derivative, D1). McCarty et al., (2002) predicted SOC for different set of sample (n=177- 257) with correlation of 0.82-0.98, RMSD =5.5-7.9. Kang (2006) found correlation of 0.9 for soil samples (n=26) to predict SOC using PLS regression model (r = 0.9) with RMSEC = 0.07 and RMSEP = 0.12.

Testing and comparison of models for SOC prediction

Using full prediction test, the minimum and maximum deviation values were compared for PLS and PCR models. PLS model for Anjeni is the best while PCR model for Maybar is the worst. PLS as a whole has better performance compared with PCR (Table 6). This agrees with findings of Kang (2006), Viscarra Rossel et al. (2006) and Viscarra Rossel and McBratney (2008).

To compare models, accuracy indices are used (Chang et al., 2001; Brunet et al., 2007; He and Song 2006; Ge et al., 2011, Kandel et al., 2011; Stevens et al., 2006). These indices are statistical parameters based on high value (close to 1) correlation coefficient (r^2), coefficient of determination (R^2) and slope values. Moreover, values of residual predictive deviation (RPD), root mean square error (RMSE), standard of error of calibration (SEC) and standard error of performance or prediction (SEP) also assesses model quality (Chang et al., 2001; Brunet et al., 2007; He and Song, 2006; Mouazen et al., 2010; Ge et al., 2011; CAMO, 2012). In this study (Tables 4 and 5) accuracy indices are better for PLS than PCR.

Root mean square error of predication (RMSEP) is expressed in the same units than the variable of analyses (soil organic carbon, g kg^{-1}). Standard error of prediction/performance (SEP) assesses the ability of the model to predict SOC. Standard error of calibration (SEC) is the standard deviations of all the points from the reference values in the calibration set (Stevens et al., 2006). Best model has lowest SEP. That means, SEP indicates variation in the precision of predictions (Mouazen et al., 2010; CAMO, 2012). In this study (Table 4 and 5) SEP values are better for PLS than PCR.

R^2 values for prediction of soil properties are rated as very good (>0.81), good (0.61-0.8), fair (0.41-0.6) and poor (<0.4) (Viscarra Rossel and McBratney, 2008). The value of R^2 varies from 0.1 (Maybar) which is rated as poor to 0.9 (Anjeni) which is rated as very good (Tables 4 and 5). R^2 values reflect that Anjeni has good predictive ability for SOC while the three site model has is fair. But, Maybar and Gununo models are too poor to be used for prediction.

Ratio of standard deviation to RMSEP or RMSEC is RPD (Chang et al., 2001; Stevens et al., 2006; Mouazen et al., 2010; Kandel et al., 2011; Ge et al., 2011). RPD is used as indicator of predictive ability of models. Genot et al., (2011) indicated that RPD is used to compare samples from diverse variability. Rating shows that RPD< 1 is very poor model, RPD from 1 to 1.4 is poor model, RPD from 1.4 to 1.8 is fair model, RPD from 1.8 to 2 is good model, RPD from 2 to 2.5 is very good model and PRD >2.5 is excellent model (Mouazen et al., 2010). The value of RPD in this study varies from 0.7 (Maybar) to 3.6 (Anjeni).

Values of r^2, R^2, slope and RPD (Tables 4 and 5) shows that PLS has better predictive capacity compared with PCR. Finding in this study agrees with PLS better performance over PCR as indicated by Mouazen et al. (2010) and Viscarra Rossel et al. (2006).PCR and PLS are related techniques and in most situations prediction errors will be similar (Viscarra Rossel and McBratney, 2008), though PLS has comparatively lower predication error. As a whole, taking in to account the two rating methods based on R^2 values as suggested by Viscarra Rossel and McBratney (2008) and RPD value as suggested by Mouazen et al., (2010), Anjeni model is excellent while Gununo and Maybar models are poor. Maybar model has least predictive capacity and rated as very poor based on the above two rating parameters.

Conclusions

Visible-near infrared reflectance (VisNIR) diffuse reflectance spectrometer (DRS) method was used to predict SOC in Ethiopia. Analytical data shows that SOC (g/Kg) from three sites (n=275) has a mean value of 2.0 with 1.2 standard deviation. Most frequent value of SOC is 2.5 g/Kg with a minimum of 0.05 and maximum of 6.7.

PCA score plot shows first two components accounts for a minimum of 96% variation. The closeness of the samples in score plot shows samples similarity with respect to the first principal components.

Although performance of PLS is superior to PCR, in both cases Anjeni model is the best while Maybar the worst. The poor performance of Maybar model might be

Table 4. PCR model calibration and validation results.

Site	Spectra treatment	Process	n (samples)	PCs	Correlation (r)	Slope	Offset	Final R^2	Final RMSEC/ RMSEP	RPD
3 sites	Raw spectral	CAL	193	10	0.71	0.51	0.96	0.51	0.89	1.3
		VAL	82	10	0.68	0.42	1.19	0.46	1.07	1.2
	De-trend	**CAL**	**193**	**10**	**0.75**	**0.57**	**0.83**	**0.57**	**0.83**	**1.4**
	Figure 3a	**VAL**	**82**	**10**	**0.76**	**0.51**	**1.96**	**0.57**	**0.95**	**1.2**
Gununo	Raw spectral	CAL	68	7	0.52	0.40	0.95	0.22	0.84	0.9
		VAL	28	7	0.52	0.40	0.95	0.22	0.83	0.9
	De-trend	**CAL**	**68**	**7**	**0.59**	**0.35**	**1.24**	**0.35**	**0.66**	**1.2**
	Figure 3b	**VAL**	**28**	**7**	**0.55**	**0.48**	**0.78**	**0.20**	**0.80**	**1**
Anjeni	Raw spectral	CAL	69	10	0.90	0.81	0.29	0.81	0.41	2.
		VAL	29	10	0.65	0.52	0.78	0.46	0.83	1.3
	MSC **Figure**	**CAL**	**69**	**10**	**0.90**	**0.81**	**0.28**	**0.81**	**0.40**	**2.7**
	3c	**VAL**	**29**	**10**	**0.67**	**0.51**	**0.93**	**0.42**	**0.86**	**1.2**
Maybar	Raw spectral	CAL	57	10	0.70	0.63	1.19	0.63	0.75	2
		VAL	24	10	0.45	0.23	2.73	0.18	1.89	0.7
	De-trend	**CAL**	**57**	**10**	**0.78**	**0.61**	**1.28**	**0.61**	**0.78**	**1.9**
	Figure 3d	**VAL**	**24**	**10**	**0.50**	**0.21**	**2.90**	**0.12**	**1.96**	**0.7**

CAL = Calibration, VAL = validation, MSC = multiplicative signal correction offset = intercept, R-square (R^2) = coefficient of determination, correlation (r) = correlation, RMSEP = root mean square of error of prediction, RMSEC = root mean square of error of calibration n = sample number RPD = residual prediction deviation PCs = principal components (factors).

Table 5. PLS model calibration and validation results.

Site	Spectra treatment	Process	n (sample)	No. of components	Correlation (r)	Slope	Offset	Final R^2	Final RMSEC/ RMSEP	RPD
3 sites	Raw spectral	CAL	193	10	0.77	0.59	0.80	0.59	0.81	1.4
		VAL	82	10	0.76	0.53	0.93	0.58	0.94	1.5
	De-trend	**CAL**	**193**	**10**	**0.79**	**0.61**	**0.75**	**0.61**	**0.79**	**1.5**
	Figure 4a	**VAL**	**82**	**10**	**0.79**	**0.56**	**0.89**	**0.62**	**0.90**	**1.3**
Gununo	Raw spectral	CAL	68	6	0.62	0.38	1.17	0.38	0.61	1.1
		VAL	28	6	0.62	0.38	1.17	0.38	0.61	1.1
	De-trend	**CAL**	**68**	**4**	**0.59**	**0.35**	**1.22**	**0.35**	**0.63**	**1.2**
	Figure 4b	**VAL**	**28**	**4**	**0.54**	**0.49**	**0.67**	**0.1**	**0.88**	**1.0**
Anjeni	Raw spectral	CAL	69	10	0.94	0.90	0.15	0.9	0.30	3.6
		VAL	29	10	0.80	0.59	0.55	0.70	0.62	1.7
	MSC	**CAL**	**69**	**10**	**0.94**	**0.90**	**0.15**	**0.90**	**0.30**	**3.6**
	Figure 4c	**VAL**	**29**	**10**	**0.77**	**0.57**	**0.87**	**0.55**	**0.76**	**1.4**
Maybar	Raw spectral	CAL	57	10	0.93	0.82	0.42	0.87	0.44	3.4
		VAL	24	10	0.69	0.52	2.04	0.41	1.60	0.9
	De-trend	**CAL**	**57**	**10**	**0.95**	**0.90**	**0.31**	**0.90**	**0.38**	**3.9**
	Figure 4d	**CAL**	**24**	**10**	**0.69**	**0.49**	**2.16**	**0.38**	**1.65**	**0.9**

CAL= Calibration, VAL = validation, MSC = multiplicative signal correction offset = intercept, R-square (R^2) = coefficient of determination, Correlation (r) = Correlation, RMSEP = root mean square of error of prediction, RMSEC = root mean square of error of calibration n = sample number RPD = residual prediction deviation PCs = principal components (factors).

Table 6. Testing PCR and PLS models using full prediction.

Site	Model	Spectra treatment	n (sample)	PCs	Deviation from reference (n)	
					Min	Max
3 sites	PLS	De-trend	275	10	0.5	1.9
	PCR	De-trend	275	10	0.4	1.6
Gununo	PLS	De-trend	96	4	0.3	1.7
	PCR	De-trend	96	7	0.3	2.4
Anjeni	PLS	MSC	98	10	0.1	0.7
	PCR	MSC	98	10	0.2	0.9
Maybar	PLS	De-trend	81	10	0.7	3.7
	PCR	De-trend	81	10	0.8	3.9

n = Number of soil samples PC = principal component/factors, MSC = multiplicative signal correction, Deterend = De trending, PCR = principal component regression, PLS = partial least square regression.

attributed to the 9% high leverage values and 4% potential outliers. PLS correlation (r), coefficient of determination (R^2) and residual prediction deviation (RPD) were used to compare PLS and PCR models. Models testing showed better performance of PLS compared with PCR. Based on two statistical parameter rating ($R^2$and RPD), Maybar, Gununo and three sites models are not recommended for prediction of SOC. Models were rated as very poor (Maybar) and poor (Gununo and three sites). Anjeni model, however, is excellent and can be used for prediction of SOC in Ethiopia. Anjeni model is more applicable to Nitisols, Alisols and Cambisols, soil units (FAO/UNESCO) (according to decreasing order of application).

Although there are standard protocols in soil spectroscopy for spectral measurement, gaps still exist in having clear guideline on data pre-treatment, calibration and validation for SOC prediction. The study recommends developing further predictive models to represent the diverse soil units in Ethiopia.

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