ANALYSIS OF ECO-ENVIRONMENTAL VULNERABILITY: IMPLICATION FOR BUSH ENCROACHMENT AND LIVESTOCK POPULATION DYNAMICS OF THE TELTELE RANGELAND, SOUTHERN, ETHIOPIA

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Abstract. Eco-environmental vulnerability is one of the challenges of Teltele rangeland Southern, Ethiopia. This research aimed to analyzing change of grassland area to bush covered area via remote sensing method using NDVI values, temperature, perception, land use change and the local community background knowledge from 1990-2015. The eco-environmental Vulnerability Integrated Index (EVSI) for each class,1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2015 shows an upward trend. That is 1.59, 2.61, 2.91, 2.67 and 2.8 respectively for each interval. The higher EVSI value, is the more serious impact of eco-environmental vulnerability or encroachment of the bush plant coverage. Based on the NDVI data, the net change in open bare grazing area to bush covered vegetation over the past 25 years was 43.2%. The key factor in the rapid encroachment of bush vegetation was the frequency of drought (El Niño), causing a decline in the population of pastoralist community of Teltele were faced with poverty due to their livelihood. As a result, trend of livestock population dynamics shows a decreasing in the pattern. Based on the current results, the design of the scientific management techniques for eco-environmental vulnerability and raising awareness in the local community will be the priority area for further studies.
Keywords: *NDVI, invasive species, degradation, pastoralist, remote sensing*

Introduction

Environmental vulnerability has been defined as a significant impact observed due to the variation of the mean state of climate relevant variables such as temperature, precipitation and wind over a period of time (IPCC, 2007) and exposure to climate change, sensitivity and adaptive capacity (IPCC, 2001) and became a major threat to humanity (Watson et al., 1998; O'Brien and Levchenko, 2000). Mainly in Africa, the impact of vulnerability to climate change is difficult compared to other developed countries, because of the lack of economic, development and institutional capacity (IPCC, 2001; Sithole and Murewi, 2009). Poverty, human diseases and high population density with high demand for food, water, and livestock forage are among the major impact due to climate change (Davidson et al., 2003; Thomas et al., 2000; Masike and Urich, 2008). Arid and semi-arid environments of most part of the world including Ethiopia, mainly characterized by high inter-annual rainfall variability and reoccurring

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droughts (Ellis and Swift, 1988; Mogotsi et al., 2012) which are likely to be exacerbated by climate change (IPCC, 2013). And also, the Teltele rangeland, Southern, Ethiopia highly faced such climate impact like drought and flooding. In the rangeland areas livestock production sector as a livelihood option is one key sector which will bear the brunt of these climatic conditions fluctuation (Stige et al., 2006; Sithole and Murewi, 2009).

Livestock rearing and farming are the most important source of income for the people lived in arid and semi-arid rangeland area in most parts of the world. In most rangeland area of Ethiopia, including Teltele rangeland livestock rearing is the direct source of income for local pastoralist communities (Bongers and Tennigkeit, 2010). It is a home for the livestock production sector as a woreda and national level with 95% of the family income source rely on livestock in the area (Tache and Oba, 2010). According to report of different studies (Li et al., 2012; Shapiro et al., 2017), estimated direct contribution of livestock production in lowland pastoral systems of Teltele in combination with other part of Ethiopia to agricultural growth domestic product (GDP) and national GDP to be 39 and 17%, respectively. The area supports more than 70,500 families with an annual population growth rate of 2.5–3% (Dalle et al., 2015). Livestock production dominated by the Borana breed and it was been the major source of livelihood for Teltele pastoralists. This breed is one of the most productive, fast-growing and fertile as compared with other indigenous cattle breeds in Ethiopia (Elias et al., 2015). Cattle, goats, sheep, camel, mule, donkey and horse are the main livestock species reared on the study site. According to central statically agency report in, 2014 to 2015 there were a total of 499,719 (197,876 cattle, 185,846 goat, 105,158 sheep, 4 horses, 65 mule, 9,704 donkey and 1,062 camel) livestock population were recorded in Teltele rangeland. Livestock play a crucial role in the subsistence economy, culture and religion of pastoralists in Teltele rangeland, and represent both social capital and an insurance against disaster (Angassa and Oba, 2008). Teltele pastoralists are used their indigenous knowledge for rangeland and water resource management strategies.

Now adays, threatening factors mainly due to environmental and socio-economic changes may severely affect ecosystem services of the rangelands, such as forage supply and carrying capacity potential in worldwide and also highly happened in Ethiopia rangeland area, particularly in Teltele rangeland (UNEP, 2009; Augustine, 2010; Brink et al., 2014). Climatic factors like drought and unpredictable rainfall have a huge impact on the rangeland’s vegetation status and its productivity (Neely et al., 2009; UN, 2011). In several part of Ethiopia, including Teltele, mean annual precipitation is projected to decrease by 10 to 20% (Haile et al., 2010; Elias et al., 2015) and climate change is therefore, expected to threaten the pastoralist livelihoods. Under which local circumstances, changing rainfall characteristics may limit the ability of pastoralists to secure their livelihood sustainably if they depend only on local forage resources is an open question (Angassa and Oba, 2008). Drought also one of the major causes for rapid encroachment of Bush plant species, since this species can easily adaptive potential with environmental change as compared with native plant species. The vulnerability of pastoralists is becoming severe due to the recurrent occurrence of climate change, due to both climatic and anthropogenic factors and caused the declining of carrying capacity of the rangelands (Sulieman and Elagib, 2012). Therefore, it is crucial to monitor and analyze the vulnerability of pastoral livelihoods of the pastoralists and develop adaptation strategies to reduce its impact both economic and

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social aspects (Funk and Browny, 2006; Fensholt et al., 2012). Traditionally, many pastoralists have used the installation and movement of their herds near the trading center, areas accessible to forage and water points as an adaptive method when climate change like drought occurred (Morton, 2010; Thornton et al., 2009; Sulieman and Elagib, 2012).

Furthermore, the issues like government policies, frequent impact of climate change, the increase of both livestock and human population and other political issue from time to time limits this traditional movement of the pastoralists and this make the degradation of Teltele rangeland severe in combination with climate change factors. As a result, the Teltele livestock practice, quantity and quality practice were affected by chronic interactions stocking rate and environmental variables like rainfall, soil erosion and invasive plant species encroachment and its impact is not understood and quantified yet. In order to monitor the change in vegetation, NDVI data (focused on pixel change) in combination with climate data (rainfall and temperature) evaluation was mandatory (Gu et al., 2008). However, to date, there is no any documented study data about the impact of environmental vulnerability of Teltele rangeland and associated communities entirely dependent on the rangeland. This become one of a major gap for substantiable rangeland management through balancing grazing capacity and maintain livestock performance. So, the main objectives of this study were to: (1) analyzing spatial-temporal patterns of vegetation change due to eco-environmental vulnerability by using normalized difference vegetation index (NDVI) satellite data and climatic data, (2) evaluating the effect of change in climate parameters on livestock population dynamics and (3) assessing the strategies employed by the Teltele pastoralists to reduce impact of climate cahnge. The basic question of the study was, how does environmental change become a major cause for bush encroachment in the rangeland area? How encroachment of bush plant species effect on the rangeland productivity? Simply stated, the null hypotheses of this study were: (1) environmental change does not any role for rapid encroachment of bush plant, (2) Push plant species does not have any effect on rangeland forage productivity and (3) there is no any effect on livestock population due to environmental variability.

Materials and methods

Study site

The study was conducted in Teltele Woreda of Borana zone, Southern, Ethiopia (*Fig. 1*) which covered an area of 15,430 km^2 of which 68% (10,492 km^2) is rangeland. The site was selected because it is one of the most arid parts of Borana zone and therefore, pastoral communities in this region are the most vulnerable to climatic variability. It is located 666 km south of Addis Ababa, the capital city of Ethiopia. It lies approximately between 04° 56’ 23”N latitude and 37° 41’ 51”E longitude and the altitude are about 496 m to 1500 m, the maximum altitude of 2059 m. The annual mean temperatures vary from 28 °C to33 °C with little seasonal variation. The rainfall of the site is characterized as bi-modal. Which is the 60% of rainfall occurs from March to May, and 27% from September to November with high temporal and spatial fluctuations (*Fig. 2*) (Dalle et al., 2015). The potential evapotranspiration is 700-3000 mm (Billi et al., 2015). The soil in the study site includes, 53% red sandy loam soil, 30% black clay, and volcanic light-colored silt clay and 17% silt and the vegetation mainly dominated by encroaching woody species, and those that frequently thinned,

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include *Senegalia mellifera*, *Vachellia reficiens* and *Vachellia oerfota* (Gemedo et al., 2005; Coppock, 1994). According to the latest 2015 national census report a total population of the study site was 339,460 in total (22/km^2) and of whom 179,518 men and 159,942 women. And 50,944 (15%) of its population are urban dwellers and the remaining 288,516 (85%) of the population are living in the rural area mainly on livestock rearing activity.

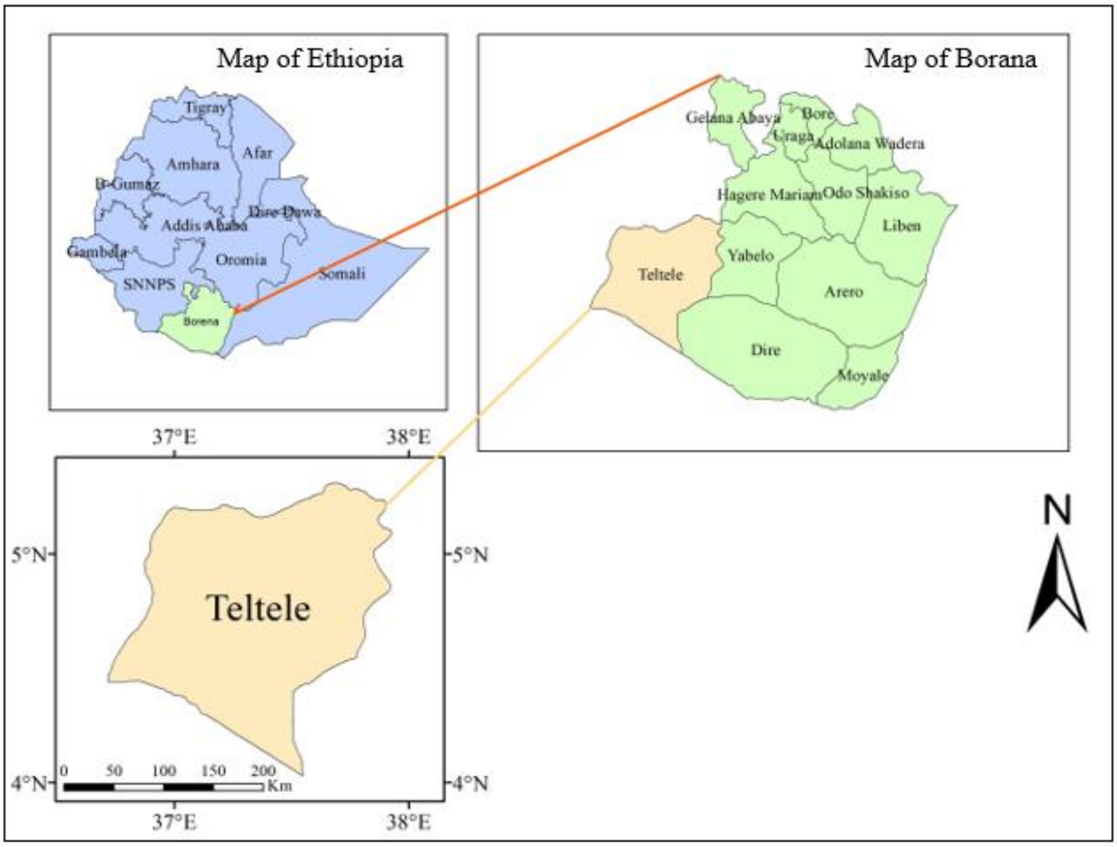

Figure 1. *Location map of the study area*

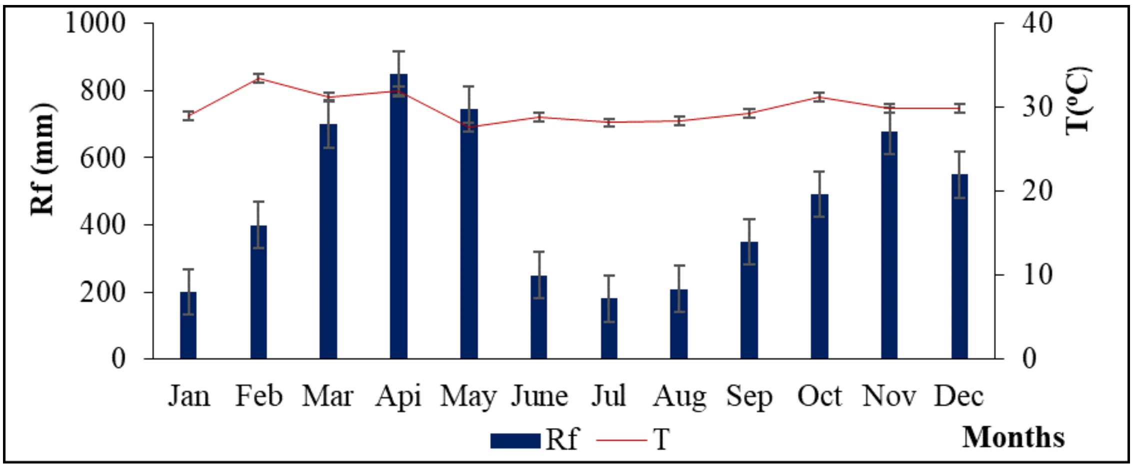

Figure 2. *Monthly mean (±SE) temperature and rainfall pattern for Teltele from 1990-2015. T = temperature, Rf = rainfall. (Source: EMA, 2015)*

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Dataset

This study combined multispectral satellite remote sensing data, in-depth fieldwork surveys and rangeland use policy analysis linked with rangeland vegetation change source. It seeks to compile some of the perceptions and experiences of local communities and individuals who are on the frontlines of climate change. The traditional weather patterns of the area, historical trends (1990-2015) in climatic variables (temperature and rainfall) collected from Ethiopian meteorological authority (EMA, 2015) and using geographical information system (GIS) and remote sensing (RS) data in order to analyze eco-environmental vulnerability. To monitoring the spatial and temporal variation in vegetation in the study area, we used the annual average of third Generation Standard Difference Vegetation Index (NDVI3g) data (1990-2015). Then from the general precipitation, temperature and NDVI data derived from the Global Inventory Modeling and Mapping Studies (GIMMS) with 8 km grid resolution of Ethiopia, we resample our study area to digital elevation model of 300 m resolution in order to get our focusing site data with high resolution, because we only need the satellite data of our study (Teltele) rangeland site (*Fig. 3*). For NDVI grid cell values we simply took the maximum, minimum and an average annual mean value in order to reduce disturbance in the trends, such as those attributable to bare soil and sparsely vegetated areas (Slayback et al., 2003; Wang et al., 2011). Vegetation maps of the Teltele district in 1990-2015 were obtained from the remote sensing data with spatial scale 1:100,000. The Landsat TM imageries acquired in five-year interval 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2015 and also changes from 1990-2015 were used for range land vegetation pattern and degradation assessment and the characteristic of Landsat used for analysis was described in *Table 1*. These years were chosen because of the availability of data, the quality of the images, and in order to compare the changes with in equal time intervals. And also, further, verification was done through interviews and semi-structured focal group discussions with the local pastoral community and stakeholders for the accuracy of the rangeland current status and vegetation degradation images analyzed by using ArcMap 10 software.

Socio-demographic profile of the respondents

To understand the level of pastoralists awareness on the changing climate, the types and nature of the impacts, the changing climate variability has had on the livestock production, the coping strategies that pastoralists have employed in reaction, as well as the existence of external support to help the pastoralists adapt to the climate change impacts was collected through both informal and formal group discussion with pastoral community, individual and key informant. Interview questionnaire were composed of both structured and unstructured questions and basically focused on the issues such as: How climate change trend looks like on the study area, its influence on the grazing lands and local communities, the possible causes, the main problems of climate change on the range land, traditional coping mechanisms and extension service provided against these condition were explored. The discussion was used as a means of creating awareness in the pastoralist's community, generating ideas regarding issues related to rangeland management and coping mechanisms. In order to obtain a representative sample data for the study site, both stratified and clustered sampling methods were applied for all pastoralists and stakeholder selection. Since, the pastoralists commonly live in scattered way, rather than nuclear clustering of households was necessary.

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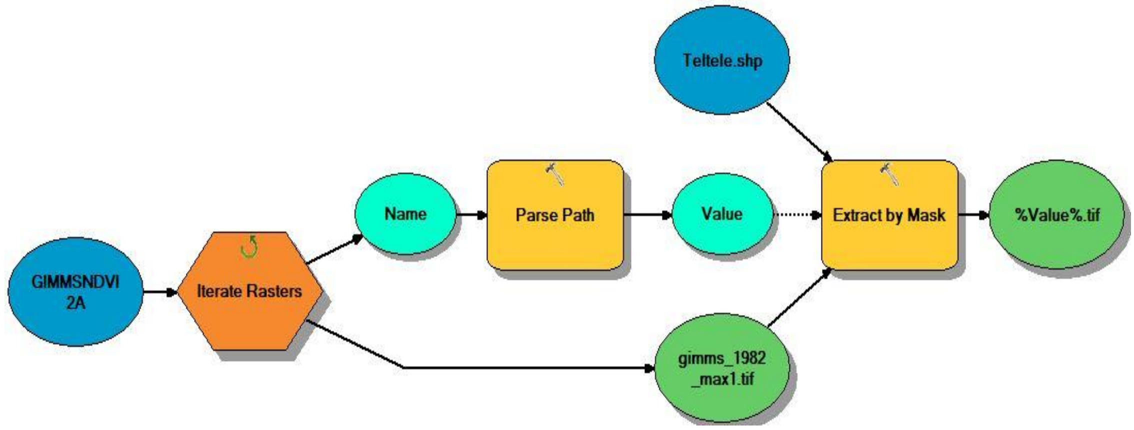

***Figure 3**. Schematic representation of the model we used to extract and resample our study area data*

***Table 1.** Characteristic of Landsat used for LULC change analysis*

Data	Year of acquisition	Bands/color	Resolution (m)	Spectral resolution/bands
Landsat Thematic Mapper (TM)	1992, 1995, 2000, 2005, 2010, 2015, 2019	Multi-spectral	300	Band 1-5: 0.45-1.75 Band 6: 10.4-12.5 Band 7: 2.08 – 2.35

A total of 104 (69 males and 35 females) head of households were interviewed. From this key informant purposefully selected based on age (>35), experience, training participation and way of better life based on the recommendation of the local people and stakeholders (n = 20 in total, 14 males and 6 females) with addition of 4 government official worker stakeholders (3 males and 1 females) from different sectors (livestock, agriculture, tourism and meteorology), and the remaining 80 (52 males and 28 females) were selected randomly based on the our clustering. The total number of sampling population was mainly depending on our time and budget, but we tried to made it representative of the study site. Such approaches have proven effective with Ethiopian pastoralists like Teltele because these people place very high cultural value on livestock and have well developed mental skills to track animal inventories (Solomon and Coppock, 2002). The trends of the priority livestock (cattle, goat, sheep and camel) population dynamics and production performance indicators, such as birth rates, death rates and off-take rates for each livestock species, was collected from statistical abstracts of Teltele district, southern Ethiopia for the last twenty-five (25) years. The general framework methodology we adopted to identified the change of precipitation, temperature and the vegetation index change using NDVI was summarized in *Figure 4*.

Analysis of eco-environmental vulnerability change trend

In order to understand the cause of vegetation change in the study area, the general trend of environmental viability was assessed through both interview and group discussion with the local communities in addition to the satellite data. Spatial analyses of vegetation, precipitation, temperature and NDVI change were done using ArcMap

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10.3.1. Study site statistics function was used to extract NDVI values of the Regions of Interest (ROIs) from corresponding vegetation types for all months from January to December for the years 1990-2015. The data were coded, tabulated and analyzed using Microsoft excel and SPSS. The data collected from the officials and key informants were analyzed through descriptive narration and also using SPSS based on the research questions. Then, the Eco-environmental Vulnerability Integrated Index (EVSI) for each category was calculated using *Equation 1*.

$$\mathrm{EVSI}_j = \sum_{i=1}^{n} P_i \times \frac{A_i}{S_j} \quad \text{(Eq.1)}$$

In this formula, n = is the number of degradation level (in our case n = 4, that was described under result section in *Table 3* and *Fig. 9*), EVSIj = the EVSI in unit j, A_i = the occupied area of degradation level i in analysis unit j (area of pixel for each level or assign number), Sj = the area of analysis unit j (total area of analysis), and P_i = is the leveled or assign number value of level i (in our case i = 1, 2, 3, 4) (Gunnula et al., 2011; Yang et al., 2016; Xu et al., 2010; Ainong et al., 2006).

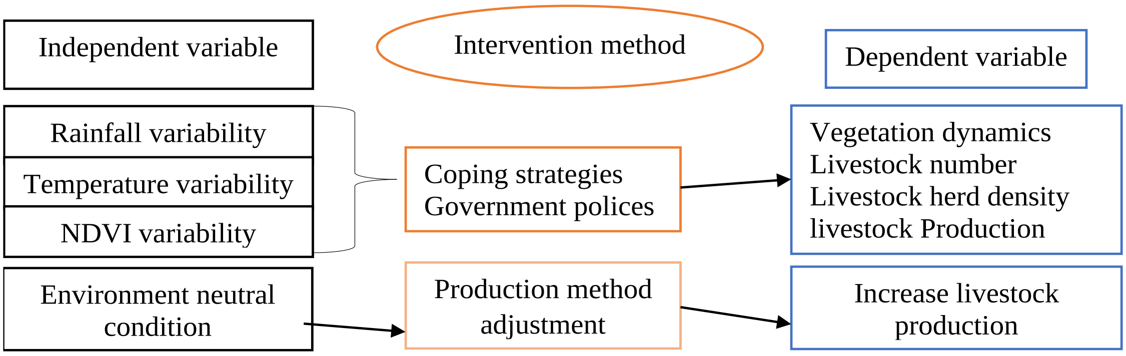

Figure 4. *Conceptual framework for this methodology (developed by Author, 2020)*

Results and discussion

Socio-demographic characteristics of the respondents

The respondents’ gender, occupation and level of education were some of the main demographic feature’s that the authors considered for this study to remove the biased from our data.

During data collection we also tried to considered the gender proportion into account within the participants. But, in the area and in the country in general, the activity of field work including farming, livestock rearing and other outside activity mainly performed by male household, whereas, females are mostly focused on housework including keeping children, prepared food and others. As a result, the experience and knowledge about rangeland status mostly obtained from male households. However, we tried to included and balance gender involvement during our data collection i.e. 66% of males and 34% of females of the total number of participants. This distribution made it possible to understand the perception and coping method of adaptation to climate vulnerability of male and female pastoralists. Then, the level of education is one of the

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basic factors on the socio-economic practice within a family and as we have seen from *Figure* 5, the majority of pastoralists (78%) were illiterate followed by primary education (11%) level. This is because of the educational system was still not well exercised and adapted, due to lack of awareness about the value of being educated and these leads the community did not enforce to accesses the infrastructure with in the pastoral community based on the data obtained from the respondents. And also, to some extent, the situation has occurred in some way to other parts of the country. As a result, most of the livelihood community that depends on livestock occupation has been dispossessed, and this was the major factor that caused most of the pastoralists source of income to depend on livestock rearing (66%) followed by running their own business beside it (19%). Considering, their educational level, our questioners were focused on their experience observation and impacts based on their expectation, rather than scientific explanation.

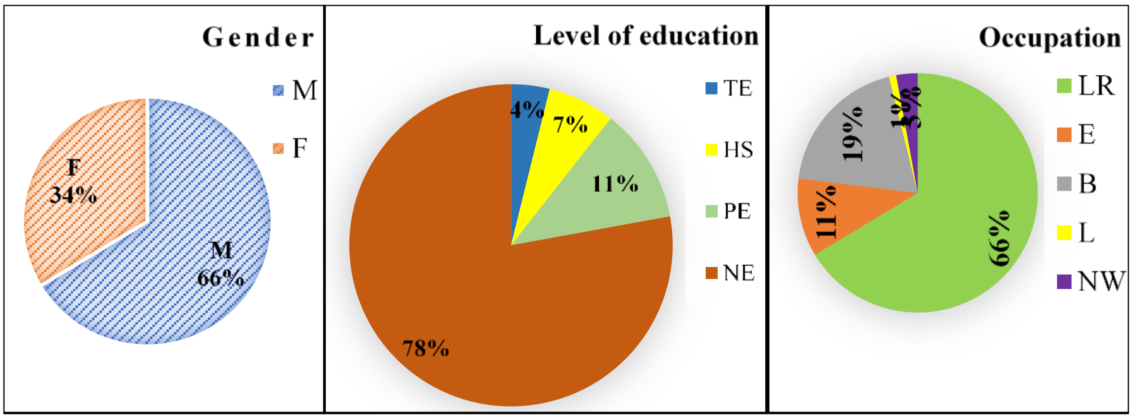

Figure 5. *Distributions of respondent's demographic characteristics. (M = male, F = female, TE = tertiary education (college and university), HS = high school, PE = primary school, NE = not educated, LR = livestock rearing, E = employment, B = business, L = labor work, NW = Not known work)*

Analysis of eco-environmental vulnerability

Trend, pattern and impact of environmental vulnerability based on respondent's Perception

In order to understand the trend, pattern and followed impact of climate change (mainly rainfall and temperature) from their experience and daily activities, respondents were asked the following basic questions: (1) Is there any change observed in the recent year? (2) What was the nature of the change? (3) what was the impact of the change? And (4) What is the possible reason that cause the change? Their ideas and response were described in *Figure 6* and *Table 2*.

From *Figure 6* we clearly understand that majority of the respondents confirmed the occurrence of climate change (93.3 and 89.4%), trends of change (97.1 and 92.3%) and its associated impact (98.1% and 84.6%) for both rainfall and temperature respectively. Respondents mentioned that climate change was significant impact on forage production and water availability in the rangeland, that affected their livestock health and caused death and a decrease in the number and of productivity, which had a direct effect on their livelihoods.

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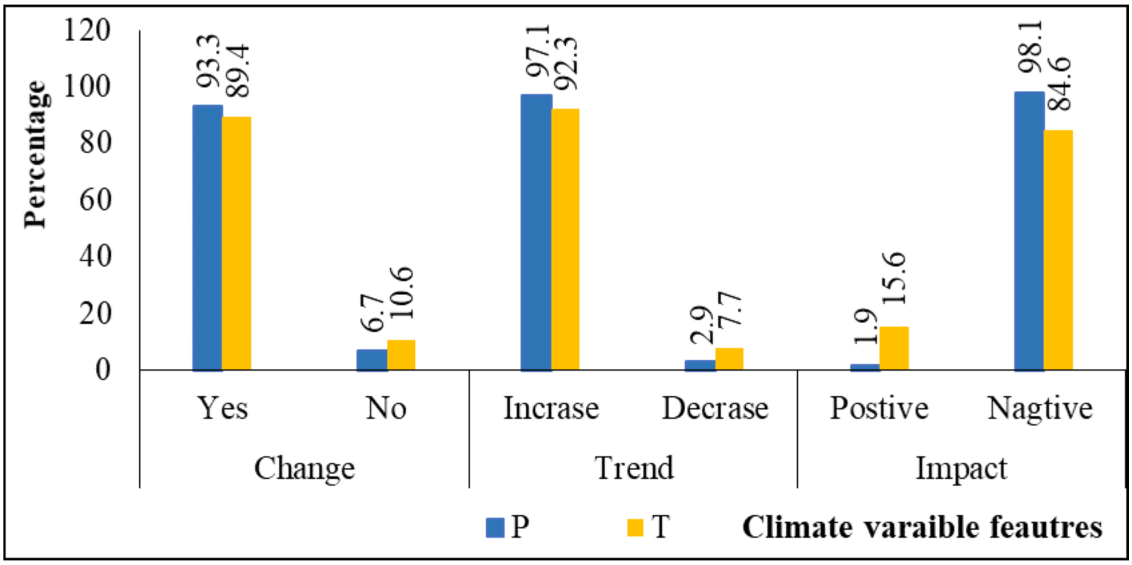

Figure 6. *Respondents data with trend, pattern and impact of eco-environmental vulnerability. P = precipitation, T = temperature*

Table 2. *Drivers that cause climate change in Teltele rangeland*

No.	Possibilities	Number of respondents (n)	Percentage (%)
1.	Drought	24	23.0
2.	Increase population number	16	15.4
3.	Poor social- interaction	7	6.7
4.	Bush encroachment	35	33.7
5.	Gods plan and nature	6	5.8
6.	Government policies	11	10.6
7.	Insects and disease	5	4.8
	Total	**104**	**100**

With regards to the major drivers of impact of climate change on vegetation in Teltele rangeland, the bush encroachment ranked as the primary reason (33.7%), followed by drought (23%) and increase of the population both human and livestock in the district (15.4%) without additional land provided (*Table 1*). Government policies have also had their own impact on the livelihood of pastoralists in Teltele, which promote transformation of rangeland into cultivated land and restrict the movement of pastoralists who were traditionally used to coping climate change impact. Not only this but also government policies also caused for the introduction and expansion of invasive plant species on the rangeland area due to a reason for watershed activates before scientifically assessed its long-term impact. Most of the invasive bush species on Teltele rangeland introduced and expanded due to the above-mentioned reason. And also, the policies restricted from eradicated all invasive plant species from the rangeland by the local communities in the name of forest deforestation activates and punished the one who participated on such activity. Further, free movement of pastoralists for searching food for their livestock from one area to another area was restricted and enforced them to spent in specific grazing area for a long period of time and caused both degradation

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and scarcity of forage for their livestock. Both productivity of rangeland and their livestock decline and faced for poverty and scarcity of food. As a result, such government policies on the study area became caused for climate change and degradation of rangeland because of rapid encroachment of non-native spices. But there is still a big gap under the term of climate change, rather the pastoral community thought that it was due to God's plan and to the nature which could be intended to punish us. This was an indicator of community's low awareness of the climate change with which the whole world is grappling with and our data are consisted with the data reported by Han et al. (2008).

Effect of climate change on vegetation pattern

Among the major driving factors of vegetation degradation in arid and semi-arid rangeland area like Teltele, a frequently occurrence of climate change, mainly a decrease in rainfall pattern and increase of temperature. The remote sensing data from these results indicated that the annual temperature was going to increase on an alarming scale and on the contrary annual rainfall rate shows a decline trend (*Figs. 7* and *8*). This told us in the vegetation of arid and semi-arid rangeland that the eco-environmental vulnerability was high and resulted in vegetation degradation and followed the decline of livestock population dynamics and faced a change in the pastoral livelihoods. Then, our result directly related to the data reported by Lin et al. (2013). In the pasture rangeland of Teltele, the frequency of eco-environmental vulnerability creates favorable conditions for rapid encroachment of invasive bush plant species which compete with the native grass species. And the grazing rangeland area was becoming changed to bush covered non-grazing area (*Fig. 7*) and leads to scarcity of forage for livestock. Comparing the level of degradation of vegetation dynamics from 1990-2015, the significant open degraded area was observed in during the study period from 1995-2000, which major part of area were bare due to high drought occurrence especially in 1999 what is called El Niño occurred (1.05 °C increasing was recorded), but in 2010-2015, this open degraded area was becoming encroached by bush plant species and change to green area. The vegetation greenness changed from 1990-2015 showed appositive value. From this we can understand that in Teltele rangeland encroachment rate of invasive bush plant species was significantly rapid due to eco-environmental vulnerability of the area. Currently, this is the big challenge for pastoralist community to covered all rangeland site and also their farming area.

From *Figures 7* and *8* we can clearly understand that both precipitation and temperature variability had significant impact on the rangeland vegetation index in Teltele. The trend of temperature change from 1990-2015 showed a positive value both the highest (1.32 °C) and lowest (0.83 °C) recorded value. The rainfall pattern also showed both positive highest value (206.14 mm) and negative lowest value (-190.10 mm) and this told to us the maximum amount of rainfall showed an increased pattern and that cased for flooding and caused for rangeland degradation. Whereas, the lowest yearly recorded rainfall showed a decline trend and since lowest rainfall is very essential for vegetation growth and also for recharge ground water table that is important for increasing both water and forage availability for livestock. But the normal rainfall distribution became decline and this is the real cause for degradation in Teltele rangeland happened currently. In the period between 2000 and 2005 the rainfall distribution was recorded highest both yearly maximum (863.15 mm) and minimum (189.58 mm) and the highest flooding that highly degraded the rangeland area was

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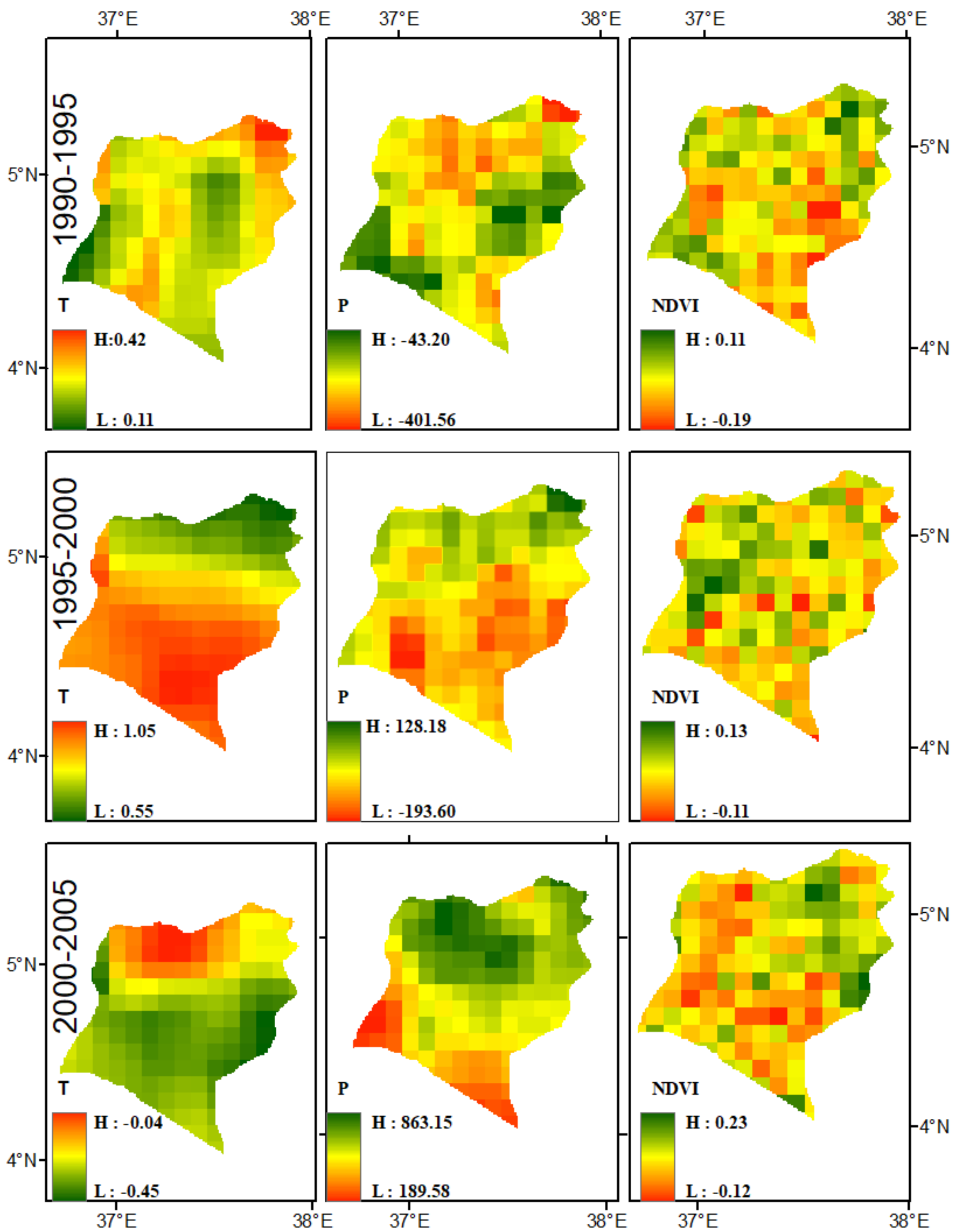
recorded and at the sometime encroachment of bush plant species got favorable reached highly occupied most part of the rangeland (highest NDVI value = 0.23) and less competition from native plant species (*Fig. 7*). The net change of both highest and lowest recorded temperature value in Teltele rangeland from 1990-2015 was showed significantly increasing pattern. The mean highest rainfall value trend also showed an increasing and this up normal maximum rainfall amount caused for rapid degradation of rangeland soil and other resource, but the normal or minimum rainfall distribution showed a decreasing trend. Therefore, net changing trend of rangeland vegetation greenness also showed variation with related to highest and lowest value.



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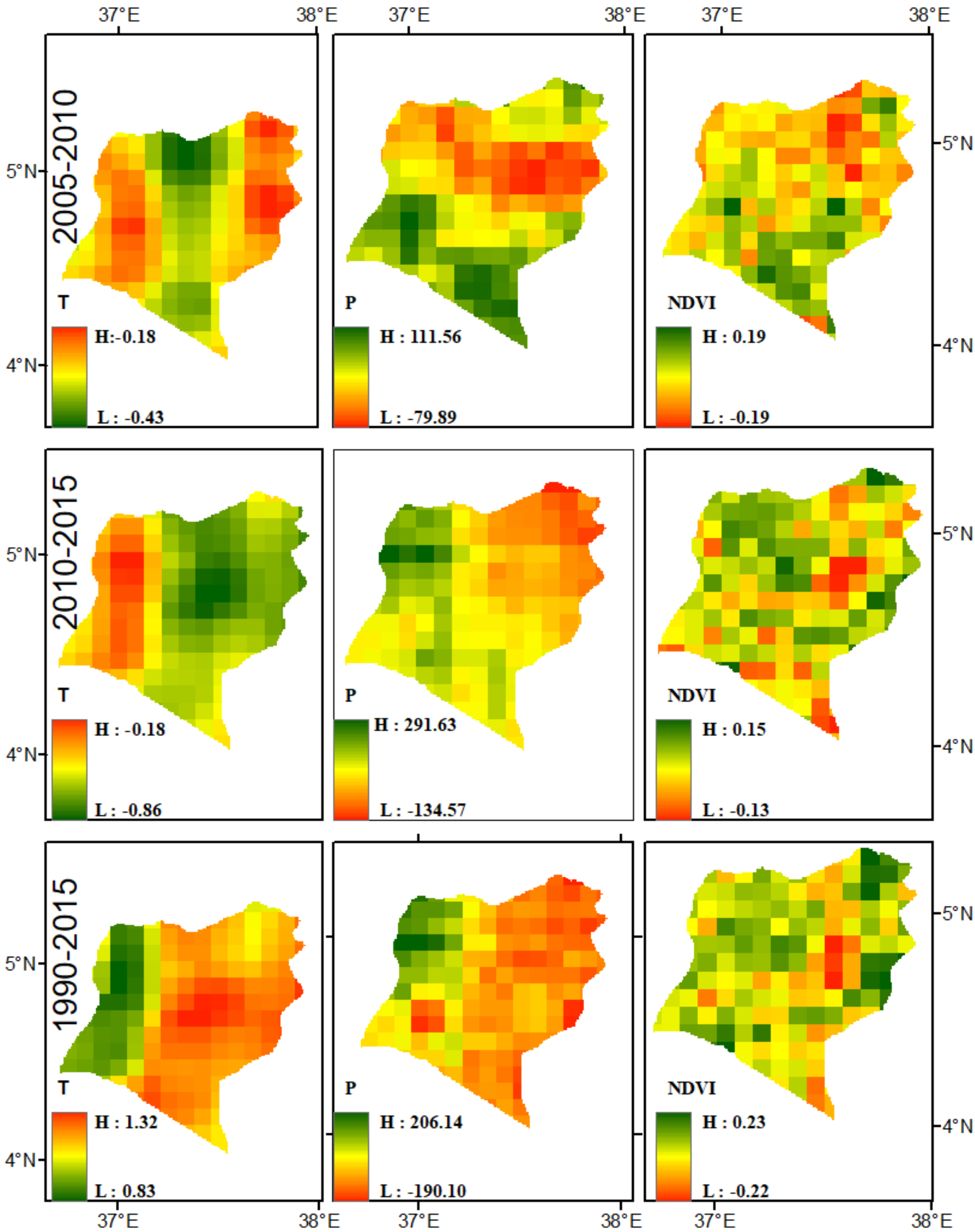

Figure 7. *Temperature, precipitation and NDVI change trends for Teltele rangeland from 1990-2015, T = temperature, P = precipitation, H = high value, L = low value*

The highest NDVI greenness value highly related with encroached bush plant species that occupied major area and easily detected by satellite data, showed appositive value (0.23) indicated that rapid encroachment of non-native spices on the Teltele rangeland. Whereas, the lowest NDVI value showed a decreasing trend (-0.22) and this highly related with the grazing grass species and showed a decline due to the mentioned eco-

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environmental factors. This variation depends on the fluctuation patterns of climate change (rainfall and temperature). Mostly, if the temperature was low and rainfall was high (2000-2005), the rangeland vegetation index (NDVI) value was high. Since, the rangeland vegetation phenology was high during the periods of heavy rainfall. The general trend of the vegetation index dynamics of the Teltele rangeland with respect to the slope analysis, was calculated based on *Equation 1* given by Yang et al. (2016) and Xu et al. (2010) using the mean NDVI value. Based on the calculated result, the Teltele rangeland had a positive (0.0055) slope value. Rangeland with a positive slope value indicate an increasing trend, while those with a negative slope value indicate a decrease trend of vegetation greenness (Cai et al., 2014). Climate change is the main driving force both either directly and indirectly for change of vegetation index, especially in the arid and semi-arid rangeland like Teltele. For instance, for rapid encroachment rate of bush plant species climate impact is the major root cases.

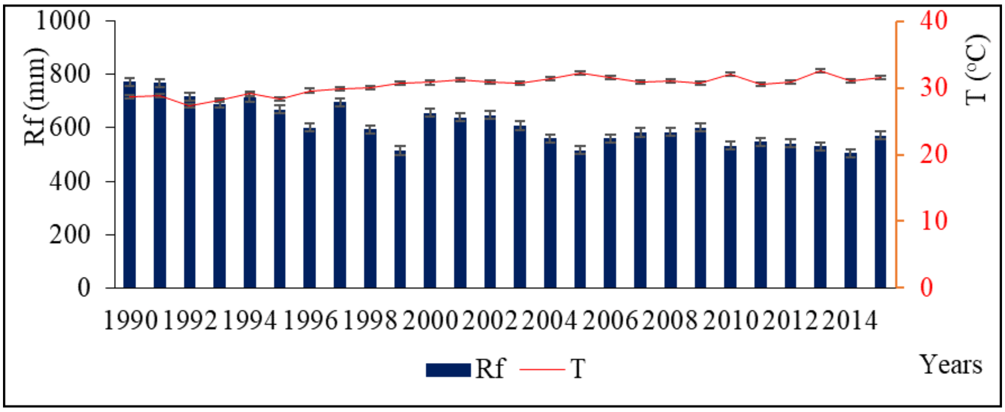

Figure 8. *Annual mean (±SE) rainfall and temperature for Teltele rangeland from 1990-2015, Rf = rainfall, T = temperature*

However, most of eco-environmental vulnerability studies focused only on the numerical change value (Amting, 1997) without considering the spatial variation of the rangeland. From our result, we can understand that the eco-environmental venerability of vegetation dynamics varies according to the slope variation. A rangeland sites with higher slope or elevation value and sites with flat were not equally impact on climate change. This means that slope steepness influences on the disturbance of livestock and human activity and the disturbance was highly observed at flat rangeland site. In addition, a combination effect of climate change was less at the highest slope, that is why the vegetation dynamics was shown a better rate at highest elevation site. The human activity and livestock disturbance in combination with climate change significantly increased the rate of rangeland degradation and showed high vegetation index change. Our result is entirely in agreement with the data reported by Potapov et al. (2008), Yi et al. (2014) and Herrmann et al. (2005).

Vulnerability grade

To scale up the observation of degradation level of our study, we used the histogram as a graphical tool to explore the statistical distribution of the classes and clusters in the attribute space (Apan, 1997) and the axes represents our categorical interval NDVI values. Taking the year from 1990-1995 as our baseline for classification since during

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this year interval, we observed the maximum level of degradation as a result, we used it as our reference to classify our interval scale (*Fig. 9*).

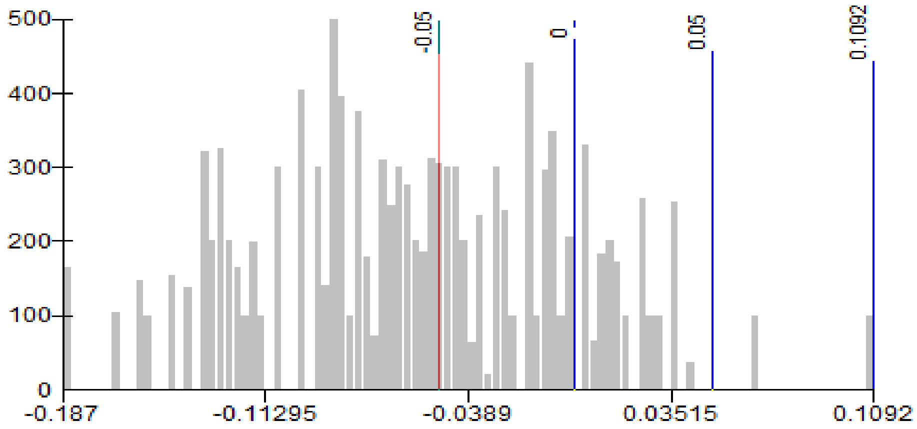

***Figure 9.** Degradation distribution histogram of the integrated index of eco-environmental vulnerability from 1990-1995*

Based on the NDVI value classified in *Table 3*, the eco-environmental vulnerability integrated index for each year interval (combined in five years) the degradation level of Teltele rangeland was clearly analyzed and generate based on remote sensing data (*Fig. 10*).

In order to understand the eco-environmental vulnerability change trend in Teltele rangeland area, the value of EVSI was calculated based on *Equation 1* and described in *Table 4*.

***Table 3.** Eco-environmental vulnerability classification interval in Teltele rangeland (based on Fig. 9)*

Degradation level	Assign number	NDVI value	Level characteristics
Over degradation	1	< -0.05	Open bare degraded rangeland area
Moderate degradation	2	0-(-0.05)	Relatively the bare degraded rangeland area sparsely covered by bush plant species
Moderate improvement	3	0-0.05	almost 50% of the degraded bare rangeland area covered by bush plant
High improvement	4	> 0.1092	More than 75% of the degraded bare rangeland area covered by bush plant

***Table 4.** The degradation proportion data of each level from the study site based on Equation 1*

Dl	1990-1995			1995-2000			2000-2005			2005-2010			2010-2015		
	Pn	%	EVSI	Pn	%	EVSI	Pn	%	EVSI	Pn	%	EVSI	Pn	%	EVSI
1	7,225	57.0	1.59	1,358	10.7	2.61	1,500	11.8	2.91	2,460	19.6	2.67	1,818	14.4	2.8
2	3,451	27.2		4,524	35.7		3,049	24.1		3,203	25.5		2,642	20.9	
3	1,793	14.2		4,240	33.5		2,962	23.4		2,615	20.8		4,151	32.9	
4	200	1.6		2,547	20.1		5,158	40.7		4,291	34		4,019	31.8	

Dl = degradation level, Pn = pixel number

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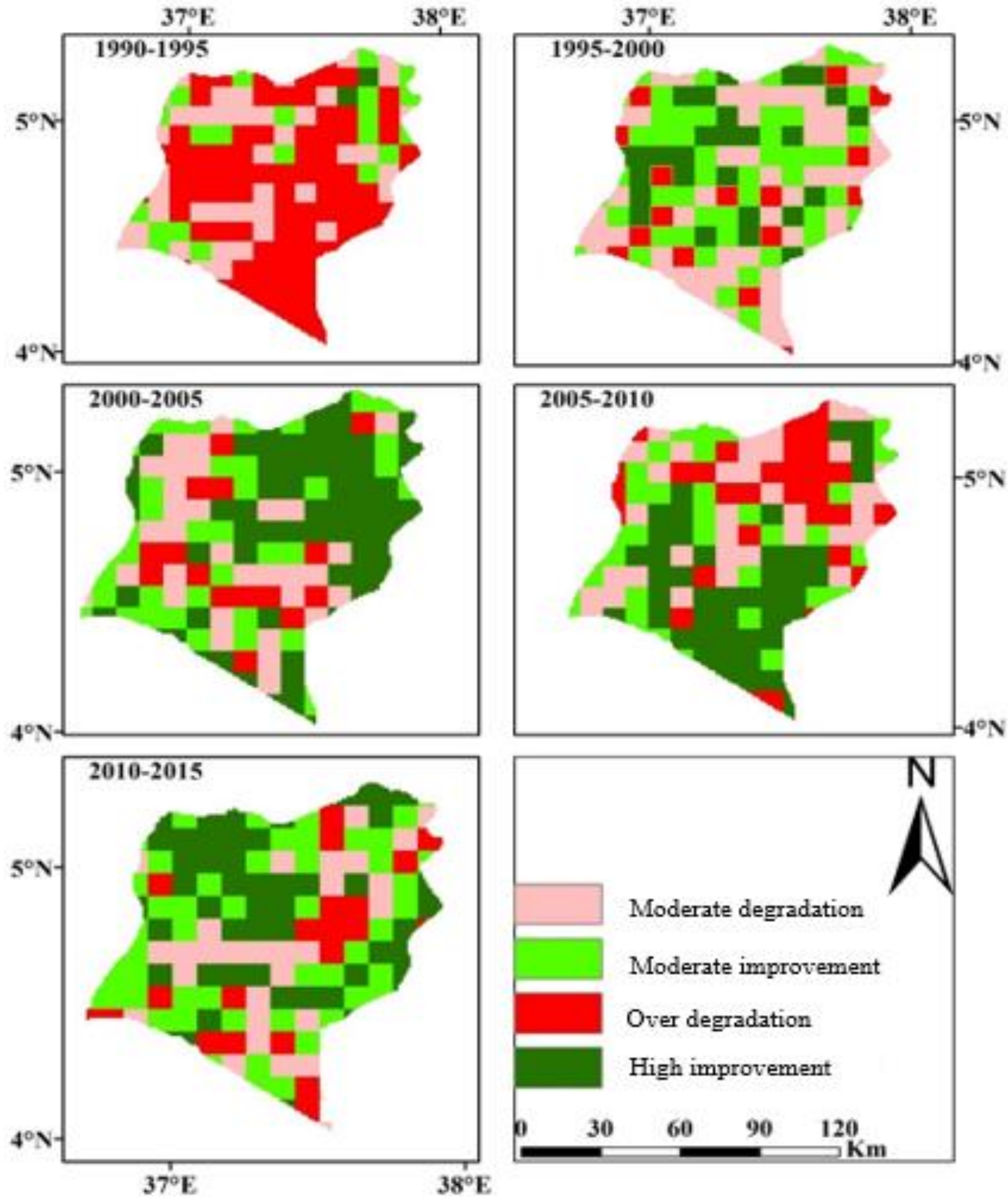

Figure 10. *The degradation distribution of eco-environmental vulnerability level in Teltele rangeland from 1990-2015*

When we have seen the general trend of eco-environmental vulnerability from *Table 4,* the rangeland situation between the time interval from 1990-1995 with an EVSI value 1.59 showed a better status from encroachment of bush plant species than the vulnerability status from 1995-2000, 2000-2005, 2005-2010 and 2010-2015 which have an EVSI value 2.61, 2.91, 2.67 and 2.8 respectively. The higher EVSI value indicated the more serious impact of eco-environmental vulnerability and the lower EVSI value indicated that impact of eco-environmental change is not that much significant (Ainong et al., 2005). The majority of rangeland area occupied by non-native bush plant species that is highly competent with the native grass species and caused rapid decline of forage biomass in our Teltele rangeland.

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The pattern of degradation level or the rangeland area occupied by the invasive bush plant species looks like: (1) from 1990-1995, level 1 degradation was highest (57%) followed by level 2 (27.2%), level 3 (14.2%) and level 4 (1.6%). This indicated that the major degraded Teltele rangeland area during from 1990-1995 was bare area and was not occupied by the current rapid encroached bush plant species, (2) from 1995-2000 the major bare degraded area of the rangeland encroached by the bush plant species and the degradation level goes from level 1 to level 2, i.e. level 1(10.7%), level 2 (35.7%), level 3 (33.5%) and level 4 (20.1%) and this indicated that majority of bare area replaced by encroached non-palatable plant species, (3) from 2000-2005 the major encroachment rate (level 4) of bush plant species was observed (40.7%) followed by level 2 (24.1%) and level 3 (23.4%). This is because of the occurrence of a severe drought called El Niño in 1999 which facilitates the encroachment rate of bush plant species while the native grass species was highly degraded, due to effect of drought, high competition with those encroached plant species and overgrazing, (4) from 2005-2010, the encroachment rate showed an increasing trend and the local community tried to adopt the intervention techniques to reduce the degradation impact of bush plant species like mechanical cutting and others. That is why the level 1 bare area showed an improvement as compared to 1995-2000 and 2000-2015. The area coverage (in %) of each degradation level was in level 1(19.6%), level 2 (25.5%), level 3 (20.8%) and level 4 (34%), (5) from 2010-2015 the level of encroachment trend of bush plant also showed an increasing trend, level 4 (31.8%), level 3 (32.9%), level 2 (20.9) and level 1 (14.4%). Thus, this was due to the drought (El Niño) occurrence of in the Teltele rangeland during 2014 that offered an opportunity for the rapid encroachment rate of bush plant species and high degradation of the native grass species in the study area.

Livestock population dynamics

The livestock population dynamic data was collected from the district livestock office and from the respondents based on type, breed, age, sex and purpose possessed by the local communities from 1990-2015. In order to easily manage the data during analysis we, simply took five (5) year interval data (i.e. 1990, 1995, 2000, 2005, 2010 and 2015 data) and tried to see how the change looks like.

The livestock population trend from 1990-2015, showed a decline rate across in almost all livestock species found in the study area, with the exceptional of the donkey (+ sign indicates that population increment from year to year) as we have seen from *Table 5*. Then, the reduction rate was high between 1995-2000 and 2000-2005 as compared to data from other years for all species. Because of the high incidence of drought (El Niño) in the study area in 1999 and high disease occurrence during 2004 in the study site respectively, there was a loss of more livestock population through die, due to lack of forage source, water availability and diseases. The expansion of farming practices is also another major cause of declining numbers of livestock, because of loss of pasture area and this also supported by government policies which state that every livelihood should keep their own livestock in his/her own grazing site near to his/her settlement area, and not allocate more communal grazing land and mobilization from one area to another for grazing. Thus, the government has divided the communal rangeland area for independent young community for farming practice, therefore, the number of livestock per household level should be reduced. Donkey species became increase in a unique manner compared to other species found in the study area, which is also due to the impact of climate change. During the drought period the pastoral

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community collected forage and water from far distance for their livestock and for themselves. And for this purpose, donkey used as the main transportation method which is main cause for the increment of their number. From 1990-2015, the net change of livestock number was 29%, indicating that a 29% reduction of livestock number was observed as compared to the livestock population number of 2015 with 1990.

Table 5. *Total number of each livestock species from 1990-2015 in Teltele*

Study period	Livestock type							Total
	Cattle	Goat	Sheep	Horses	Mule	Donkey	Camel	
1990	270,332	290,475	132,900	67	900	6,078	3,560	704,312
1995	268,867	288,245	109,345	61	843	6,247	3,089	676,697
2000	209,123	228,389	131,000	42	612	6,978	1,978	578,122
2005	207,004	211,790	108,556	29	289	7,039	1,467	536,174
2010	199,356	193,890	106,009	15	149	8,125	1,290	508,834
2015	197,876	185,846	105,158	4	65	9,704	1,062	499,719
Population dynamics from 1990-2015 (%)								
1990-95	0.5	0.8	17.7	8.9	6.3	(+)2.9	13.2	3.9
1995-00	22.2	20.8	(+)19.8	31.1	27.4	(+) 11.2	36.0	14.6
2000-05	1.0	7.3	17.1	31.0	52.7	(+) 0.9	25.8	7.3
2005-10	3.7	8.5	2.3	48.3	48.4	(+) 15.4	12.1	5.1
2010-15	0.7	4.1	0.8	73.3	56.4	(+) 19.4	17.7	1.8
1990-15	26.8	30.0	20.9	94	92.8	(+) 59.6	70.2	29.0

Livestock population dynamics across household

Livestock population dynamics in average, across the total households found in Teltele district was shown in *Figure 11*. In order to calculate the livestock number per household, we collected the total human population data from the national census reported of Teltele district for the mean value of each 5-year interval 1990-1995 (30,156), 1995-2000 (38, 412), 2000-2005 (49,480), 2005-2010 (57,609), 2010-2015 (70,501) and divided the total number of livestock population corresponding with each year. Both the total livestock number per household level and pattern of total population number within the district was showed sharp decline trend. Livestock holdings were laid with an average of 23.44, 17.6, 11.7, 9.3 and 8 head per household from 1990-2015 each five-year interval respectively, with a net decline of 65.9% overall. This is due to direct and indirect impact of climate change, like the drought that faced the livestock for forage and water scarcity and caused for death and un planned selling of the pastoralist to their livestock to cope up from the impact. Our data directly linked with the data reported by Solomon and Coppock (2002) stated that cattle deaths were mainly due to malnutrition and starvation, with only a few due to disease, predation or other factors because of climate change impact in Borana rangeland with part of our study site.

Association of rainfall variability with livestock dynamics

The variability of rainfall in combination with other factors had a direct impact on the livestock population in the study area (Bao and Wang, 2000). The frequent fluctuation in both temperature and rainfall has also become an emergency cause of insects and other related factors that cause disease and loss of livestock in Teltele district.

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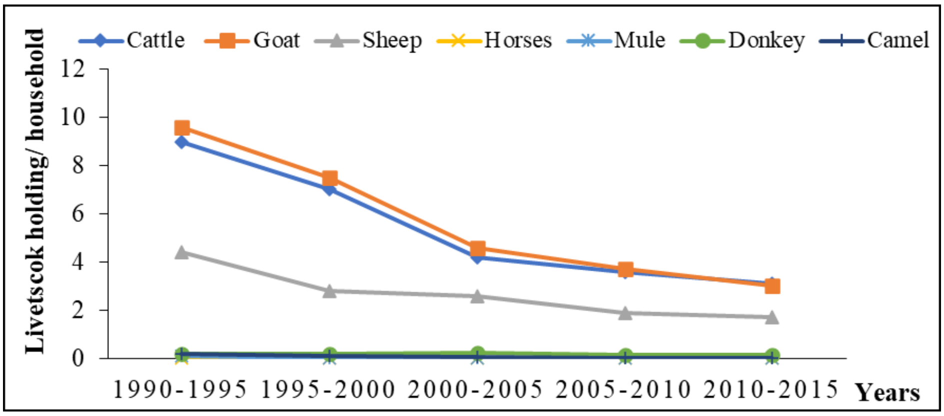

***Figure 11.** Mean value of livestock population dynamics (average number of head/household)*

As we see in *Figure 12*, livestock population decreased with the decrease in rainfall, but failed to show a significant relationship with mean annual rainfall, because of the coping strategies taken by the pastoralist community. Our result was found to be consistent with the data reported by Stige et al. (2006), Angassa and Oba (2007) and Alemayehu and Fantahun (2012). Since livestock population in the Teltele district depends mainly on the natural resource (both forage and water) found in the communal grazing area, this makes the impact of rainfall significant in combination with other factors.

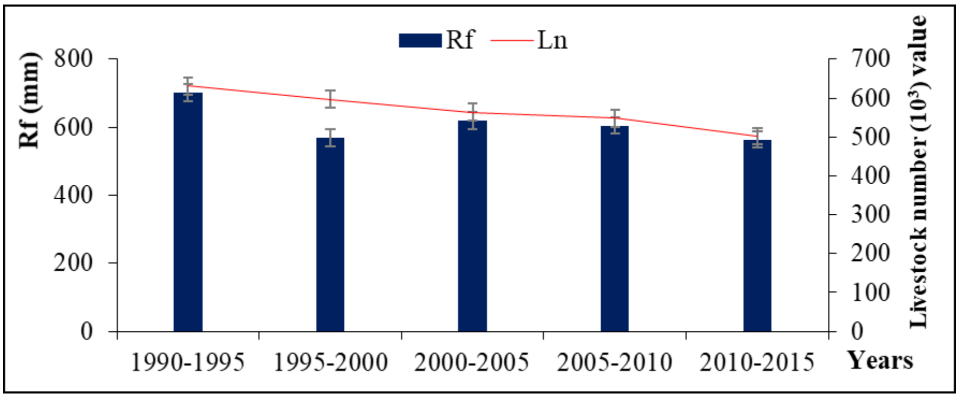

***Figure 12.** Association of mean (±SE) annual rainfall and livestock population number, Rf = rainfall, Ln = livestock number*

Correlation analysis of precipitation with grazing livestock population number

Amount of precipitation was a major impact on the productivity and general vegetation status of rangeland and highly effect on the health of the grazing site. And also, the number of livestock highly rely on the amount and distribution of precipitation both directly in indirectly. As a result, perception and livestock number had showed a significant positive correlation to each other (*Fig. 13*).

The linear regression correlation trend showed that precipitation and livestock population number had significantly (R^2 = 0.5934) positive relationship. Further, we can understand that, higher rangeland rainfall value confirmed better biomass production and used to satisfy the forage demand of grazing animal and resulted high number of grazing livestock population.

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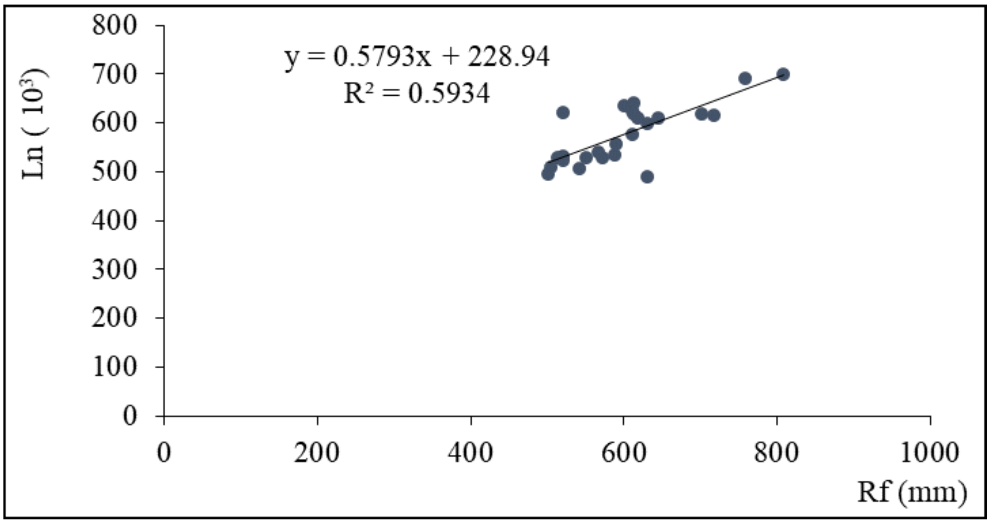

***Figure 13.** Correlations between rainfall and livestock number at Teltele rangeland, Rf = rainfall, Ln = livestock number*

Coping strategies to climatic variation on the study site

The techniques used by the local community to adapt to climate change, survive or reduce its impacts and overcome this difficult condition depend mainly on factors like: rangeland condition, livelihood income background, educational level, institutional and social network, capacity and accessibility of infrastructures such as market, road and other services (IPCC, 2007). Due to the lack of accessibility and awareness in the Teltele pastoralists community, the implementation of coping strategies was weak compared to other parts of the country. The major coping techniques listed by the local community for each possibility of climate change and how many of them applied that technique based on the respondent's data were presented in *Table 6*.

The respondents mentioned the above coping strategies listed in *Table 6*, that were implemented during climate change, mainly when strong drought (El Niño) occurred, that caused for a great impact on both the livestock and human life. During drought time the priority action taken by the pastoralists were migration or mobility to search better water and forage (77%), Sale their livestock (69%) and transport water and forage from remote area (60%) respectively. To rehabilitate rangelands infested by bush encouragement clearing or thinning the area (87%), diversified the livestock that have the capacity to eat the bush plant (69%) and used as a source of energy and income (57%) were among the priority action taken by the local communities based on the respondents data. Peace building practice through the local elders (96%) was also the primary solution used by the community to solve conflict or poor social-interactions when happened. Livestock diseases were also another challenged issue that was happened linked to climate change. The use of traditional medicine in combined with the modern (94%), was the priority action taken by the local community followed by isolating the infected animal from the herd and made it stay at home for follow-up. Moreover, to avoid further infection of the disease, selling livestock was prohibited and taken as the next strategies that was implemented in Teltele district pastoralist during climate change. Our result was highly in line with the data reported by Kgosikoma and Batisani (2014).

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Table 6. *Coping strategies used by the local communities to reduce climate impact*

No.	Drivers	Coping techniques used by the community	Frequency (%)
1	Drought	Migration or mobility to search better water and forage	77
		Conserving water through wells	38
		Transport water and forage from remote area	60
		Enclosing pasture land	39
		Sale their livestock	69
		Using water supplied by NGO Diversified their livestock to tolerate drought	29
2	Bush infestation	Clearing or thinning	87
		Burning the rangeland	24
		Used as source of income (charcoal)	57
		Herd diversification	69
3	Poor social interaction	Engaging peace building through local elders	96
		Assign local guards and take immediate action	29
		Developed traditional assets	73
		Apply government policies	75
4	Insects and disease	Using both traditional and modern medicine	94
		Isolating sick animal from the herd	76
		Reporting the case to the government	34
		Dealing with market bans and sell the livestock	48

Conclusion

Our study focuses on the impact of the eco-environmental vulnerability of the Teltele rangeland and evaluates the current situation of the encroachment of bush plant species. The eco-environmental vulnerability was analyzed using NDVI3g time series data, rainfall and temperature records. As revealed in this analysis, the variation of vegetation greenness, changes through NDVI value showed a direct correlation with the variability of rainfall and temperature. This means, that if the mean value of temperature was high, the NDVI value showed a decline, whereas if the mean rainfall value was high, the NDVI value showed high value. Thus, this tell us there is a significant relationship NDVI positively with rainfall and negatively with temperature. However, during the time when high rainfall was occurred and flooding, rangeland area became degraded and NDVI value also not significantly high related with amount of rainfall, due to consequence of degradation instead of greenness the rangeland site. Further, the rangeland vegetation showed a better status, when the rainfall was at normal standard and not caused for further degradation in the form of flooding compared with dry season. The degradation level of Teltele rangeland showed an upward trend between 1990 and 2015 mainly due to the encroachment of invasive bush plant species that almost occupied the entire rangeland area. The frequent fluctuation of both rainfall and temperature creates an appropriate condition for a rapid encroachment of invasive bush plants and, on the contrary the native grass species degraded at an alarming rate and this is the major challenge for semi-arid rangeland in Africa including Ethiopia now days. Further, the livestock population in Teltele area decreased from time to time, for this encroachment of bush plant species due to frequent drought as the primary factor based

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on the data obtained from both NDVI and the respondents. The local pastoral communities have enough information on the level of impact of eco-environmental vulnerability and practice different coping strategies to further reduce the influence on their livelihoods, but the scientific understanding still shown a gap and this is due to the lack of awareness. Therefore, based on our results, we highly recommend that the design the scientific management techniques for eco- environmental vulnerability and awareness within the local community be the priority for further studies.

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Availability of data and materials. All the data generated or analyzed during this study are included in this published article and publicly available.

Competing interests. The authors declare that they have no competing interests.

Author contributions. Available data collection, writing up and gap assessment and design was done by Yeneayehu Fenetahun, while editing and proofin: as well as supervision of the whole work during this project were performed by Professor XU-Xin-wen and Dr. Wang Yong-dong.

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