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Assessing the impact of soil moisture and land surface temperature on grasslands in Bundelkhand region of India

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Abstract
The present study evaluated the physical as well as chemical vulnerability of the grasslands in the Bundelkhand region using a comprehensive approach. The study revealed a significant decrease in grassland cover from 2014 to 2019 and a conforming effect on the moisture content of the soil, especially in the northern region, where it depeleted considerably. A very large part of the region is vulnerable to soil acidification, with existance of mild alkaline conditions, which might further change the cation exchange capacity in terms of nutrient retention. The dominanace of kaolinite as a clay mineral increased the possibility of in-congruent silicate weathering of plagioclase and feldspar, if further acidification of soil occurs. To relate the sensitivity of the active processes with the moisture avaliability in the region, downscaling of soil moisture was done at a spatial resolution of 1 km using LST and NDVI. The study outlined the importance of proper soil managmenet and prevention of sodic conditions, as a necessary step towards mitigating the harsh physical environment, for the sustenance of grasslands in the region.

Keywords: Bundelkhand, GLDAS, Grasslands, LST, MODIS, NDVI, Soil moisture

Abbreviations: EOSDIS: Earth observing system data and information service; **GLDAS**: Global land data assmilation system; **GPP**: Gross primary productivity; **LIS**: Land information system; **LSM**: Land surface model; **LST**: Land surface temeperature; **MODIS**: Moderate resolution imaging spectroradiometer sensor; **NDVI**: Normalized difference vegetation index; **SOCC**: Soil organic carbon stock; **TCI**: Temperature condition index

Introduction
Vegetation plays a very important role in controlling the overall dynamics of the ecosystem (Fisher *et al*., 2003; Cramer *et al*., 2001). In regions of acute water shortage, vegetation in the form of grasslands, become the chief component of livestock survival (Yong-Zhong *et al*., 2005; Valone *et al*., 2002). Remotely sensed data plays a very crucial role in providing the information on parameters which directly or indirectly impacts the health of the grasslands (Gillies *et al*., 1997; Carlson *et al*., 1994; Nicholson *et al*., 1994; Farrar *et al*., 1994).

Soil moisture is a critical parameter which reflects the disturbances from both the land and the atmosphere (Wang *et al*., 2007). The amount of moisture present in the soil in the liquid form is essential for sustaining the growth of the grasslands. Through satellite derived data products it is possible to estimate the moisture at different depth profiles. Global land data assmilation system (GLDAS) is a multi model ensemble which has the capability to estimate the surface as well as the subsurface soil moisture and temperature (Rodell *et al*., 2004; Syed *et al*., 2008; Chen *et al*., 2014). The GLDAS combines inputs of multiple ground based observations through land information system (LIS) with remotely acquired satellite products in real time and can have a spatial resolution of upto 1 km. Within an assmilation system the selection of an appropiate land surface model (LSM) is another key aspect.Noah-MP (multi-parameterization) as suggested by Niu *et al*. (2011) uses the input of all the key interactions happening between the atmosphere and the land and therefore, can be used for assessing the soil moisture (kg m^{-2}) and soil temperature (Kelvin) at four corresponding depths i.e 0-10 cm, 10-40 cm, 40-100 cm and 100-200 cm (Wang *et al*., 2016; Hirsch *et al*., 2014). Generally for the shrubs and grasslands (NDVI between 0.2 to 0.3) the liquid moisture and temperature in the top 10 cm of the soil profile is considered critical (Nemani *et al*., 1993; Wang *et al*., 2007).

Another factor that has been considered critical for grasslands is the Land Surface Temeperature (LST). Often LST is considered one of the most important parameter forcing the drought conditions (Karnieli *et al*., 2010). Gutman (1990) advocated the use of temperature condition index (TCI) as an indirect measure for assessing the water stress and the harshness of the drought. It has also been argued that excessive heating of the surface through climatic extremes gets amplified under depleting soil moisture conditions (Teuling *et al*., 2010). Grasslands have higher evaporation rates under increased solar radiation, therefore, are more suited under extreme temperature mitigation strategies. Moderate resolution imaging spectroradiometer (MODIS) sensor can be used at a temporal frequency of 1 day for estimating day as well as night time LST at a spatial resolution of upto 1 km (Wan *et al*., 2004; Fu *et al*., 2011).While LST has a very strong relatioship with the urban heat island (UHI) formation in densely populated cities, the same interactions are not known or studied with respect to grasslands health (Mattew *et al*., 2018; Khandelwal *et al*., 2018). To better understand the behaviour of soil moisture it becomes imperative to statistically downscale these products from moderate spatial resolution of 25 km to mediumspatial resolution of 1 km (Senanayake *et al*., 2019). Soil moisture is essentially a phenomenon related closely with NDVI and LST (Padhee *et al*., 2017). Therefore, both NDVI and LST could be used in a second order multinomial regression algorithm to produce high resolution soil moisture products (Song *et al.,* 2013). The GLDAS soil moisture products have minimum spatial resolution of 25 km. Therefore to bettter understand the soil moisture/ temperature interactions with the vegetation, it would become neccesary to have similar spatial resolution for all the three products *i.e* NDVI (Landsat 8), LST (Modis) and soil moisture (GLDAS).

In Bundelkhand, green grasslands form a major component of dietary intake for animals (Mishra et al., 2010). According to Neel and Singh., (2013) dry sub-humid tropical grasslands can sustain 3.75 cows ha^{-1} yr^{-1}. The problem of excessive grazing and subsequent reduction in grazinglands is also a very prevalant practise in the region. Excessive grazing has also led to erodibility of the soil in the region (Lal *et al*., 2006). Therefore, a temporal analysis is always required in order to identify the break point years of sudden change. In the present investigation a time series analysis was done from 2014 till 2019 using first week of May as the reference time period to assess the impact of soil moisture and land surface temperature on grasslands in Bundelkhand region of India using a comprehensive approach.

Materials and Methods

Study area: The Bundelkhand region in India extends between the Gangetic plains in the north and the Vindhya ranges in the south, occupying 7.08 million hectares of land (Patel and Yadav, 2015) (Fig 1). Although the region has a network of river confluences like Betwa and Ken, yet the region has been designated as drought prone. The region has three litho-tectonic belts *i.e*. Archean beds, Plutonic granitic beds and Intrusive mafic dykes (Avtar *et al*., 2013; Meert *et al*., 2010). The rocks in the region are believed to be of three distinct categories *i.e* Bundelkhand group (age older than 2.6 billion years), Bijawar group (age between 2.6-2.4 billion years) and Vindhyan super group (age between1.4 - 0.9 billion years) (Ahmad, 1984; Bhattacharya., 1986). The northern region of the study area is usually drier than the southern region and also recieves less rainfall. While the monsoon brings about 90% of the total rainfall between June and September, the region experiences frequent droughts (Avtar *et al*., 2013).

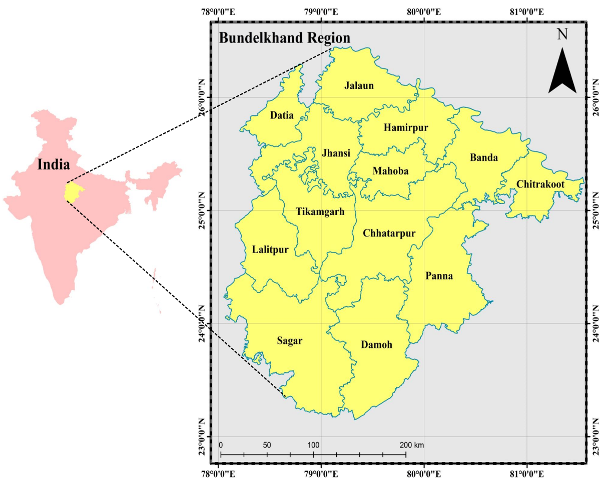

Fig 1. The Bundelkhand region of India, consisting of 13 districts, spread between Madhya Pradesh and Uttar Pradesh

Normalized difference vegetation index (NDVI): The LANDSAT 8 satellite sensor with a spatial resolution of 30 meters was used for extracting the NDVI. To minimize the interferences from the atmosphere in the process of optical image capturing, a composite of 32 days was considered. A NDVI value between 0.2 to 0.3 corresponds to grasslands and small shrubs (Weier and Herring., 2000). Therefore, for the study, a threshold value of 0.2 and 0.3 was chosen to identify grasslands based on

NDVI values (Fig 2). Higher NDVI values corresponded to higher chlorophyll concentration and represented either dense forest or thick canopy covered vegetation. In this study, NDVI values were extracted from 2014 to 2019, corresponding to the month of May. Four NDVI classes ranging from 0.2 to 0.225, 0.225 to 0.250, 0.250 to 0.275 and 0.275 to 0.3 were identified for further assessing the effect of temperature and moisture on the grassland health.

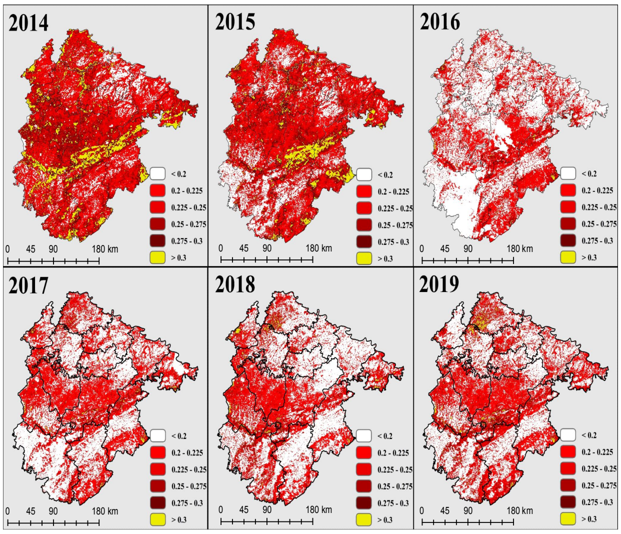

Fig 2. The spatial extent of the grasslands declined since 2014 (*represented by different shades of red colour*). The area under dense vegetation also declined (*represented by light green colour*). The other land cover types including barren lands and the water bodies (extracted before NDVI estimation) are represented by white colour

***Land surface temperature (LST)*:** To extract the LST data, Modis MYD11A1 (36 wavebands) product was used which gave day and night time LST and emissivity at a spatial resolution of 1 km (0.928 km actual) in a Sinusoidal projection. For the day LST the usual range of value lied between 7500 to 65535 with 1200 rows and 1200 columns to which a multiplicative correction factor of 0.02 was applied. The layers had a radiometric resolution of 16 bits with no additional offset requirement. As compared to LANDSAT 8, the MODIS sensor retrieved LST values based on split window algorithm which could reduce the atmospheric errors because of differential absorption in the two adjacent thermal bands and different linear and non-linear regression methods being used to estimate LST (Du *et al*., 2000). For this study, the data from Land Processes Distributed Active Archive Centre (LP DAAC) were used, which is one of the data hosting channels of NASA Earth Observing System Data and Information Service (EOSDIS) (Fig 3).

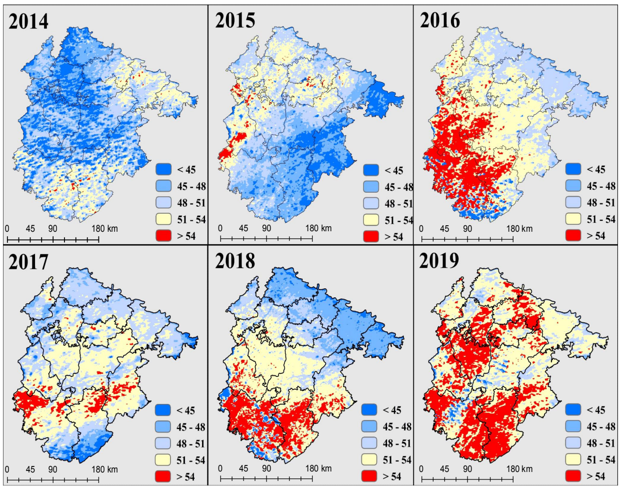

Fig 3. Land surface temperature (LST) based on MODIS (*MYD11A1.006*) sensor. The region divided into five LST zones ranging from less than 45 ^{0}C, 45 to 48 ^{0}C, 48 to 51 ^{0}C, 51 to 54 ^{0}C and more than 54 ^{0}C

***GLDAS soil moisture*:** The LSM models provide a continuous distribution of soil moisture by integrating field-based observations and LIS simulations at a spatial resolution of 0.25° (25 km) or 1° (100 km). In the present study 0.25° resolution Noah model was used which runs data from 2014 onwards (Fig 4). The monthly composite of soil moisture was prepared by averaging 3-hourly data over a month time period. Apart from soil moisture, the model also provided simulations for latent flux, soil temperature and latent heat flux. The soil moisture in the initial 10 cm depth was considered for the study based on its severity in impacting the health of the grasslands. The only problem with soil moisture was its availability at coarse resolution, therefore, a second order polynomial regression function of NDVI and LST (normalized -1 to 1) was used to downscale at 1 km resolution.

***Spatial downscaling of soil moisture*:** Both LST and NDVI were used to spatially downscale the soil moisture product of GLDAS using the regression algorithm (Kim and Hogue, 2012; Zhao and Li, 2013). The downscaling was based on co-plotting NDVI and normalized LST to spatially understand the aggregation pattern of data points in a triangular shape (Carlson, 2007). Different polynomial functions of NDVI and LST were fit in order to statistically reduce the spatial resolution of the soil moisture product (Table 1).

$$NDVI_{NR} = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (1)$$

$$LST_{NR} = (LST - LST_{min}) / (LST_{max} - LST_{min}) \quad (2)$$

$$SM_{coarse} = \sum\sum a_{ij} \,.\, NDVI_{NR} \,.\, LST_{NR} \quad (3)$$
$$SM_{high} = \sum\sum a_{ij} \,.\, NDVI_{NR} \,.\, LST_{NR} \quad (4)$$

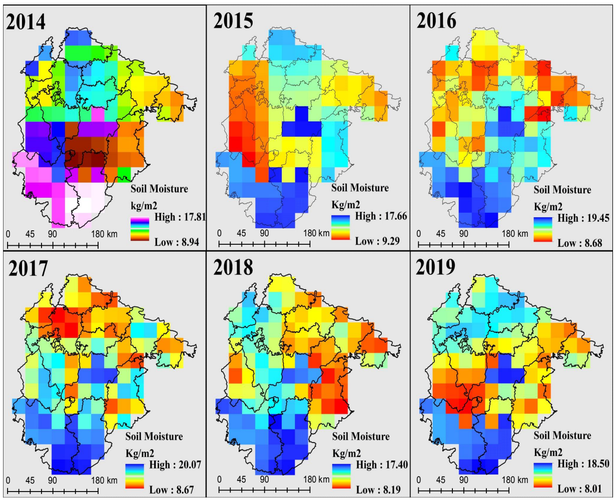

Fig 4. NASA Global Data Assimilation System (GLDAS) modelled soil moisture profile for initial 10 cm depth in kg/m^2. The NOAH land surface model (LSM) was used to classify the region based on water content of the soil

***Soil chemical characteristics*:** World Soil Information (ISRIC) database was used in order to evaluate the chemical characteristics of the soil in the Bundelkhand region. Cation exchange capacity (CEC) and pH are the two most important parameters that were retrieved at varying depths (0 cm, 30 cm, 60 cm, 100 cm and 200 cm). A high CEC under slight alkaline conditions has the ability to impact the weaterability of the rock mineral that could trigger the release of various geogenic contaminants like arsenic in the groundwater system (Singh *et al*., 2019; Singh *et al*., 2020). Potential for sustaining grasslands exists when there is high soil organic carbon stock (SOCC). High SOCC if complemented with high gross primary productivity (GPP) of the soil, denotes high possibility for the primary auto--trophs in accelerating the organic breakdown. Under these circumstances, presence of calcisols could act as a potential sink for the available hazard. Therefore, all these parameters were evaluated for understanding the combined vulnerability in addition to LST and soil moisture severity with time. Importantly all these parameters correlated with the existing soil moisture condition as with decreasing soil moisture there was a high possibility of sodic soil formation leading to increased alkanity of the soil and hence decrease in the crop productivity. Sudden changes in NDVI were also traced to these conditions changing at a sub-surface level.

Results and Discussion

***Changing grassland and soil moisture scenarios*:** An inverse technique vis-a-vis for extracting high resolution soil moisture product was applied in this study. The approach involved expressing the satellite derived soil moisture product as a function of NDVI and LST. Further sequential regression helped in quantifying the relationship in terms of variable co-efficient which were further used for deriving high resolution imagery from 2014 to 2019 (Fig 5). A critical assessment of NDVI values in 2014 and 2019 showed that grassland cover was declining since 2014 (Fig 6). In fact, in the southern Bundelkhand the change in NDVI reached to a maximum of about - 0.05, signifying an almost class shift (Fig 2). As one moves northwards in the study region the change in the NDVI values further diminished. The maximum positive and negative growths recorded in NDVI were - 0.20 and 0.05, respectively. LST too, witnessed a decreasing trend, where the southern region is experiencing a maximum change in day LST. The increase in LST with corresponding decrease in NDVI validated the hypothesis that reduction in grasslands in changing the heat cycle of the region. In southern Bund-

Table 1. Downscaled coefficients obtained after second order regression from coarse resolution soil moisture product of GLDAS

Coefficient(a_{ij})	2014	2015	2016	2017	2018	2019
NDVI	132.62	-366.98	2159.773	36.96	203.50	249.89
LST_{NR}	76.66	-263.28	795.5615	171.91	61.16	43.27
NDVI x LST_{NR}	-496.87	1923.80	-8291.52	-2505.23	-802.70	-231.19
$NDVI^2$ x LST_{NR}	512.58	-3307.42	19848.65	7482.07	2097.46	71.81
$NDVI^2$ x LST_{NR}^2	204.33	2840.88	-15920.70	-8384.08	-1381.96	3547.42
NDVI x LST_{NR}^2	184.63	-1747.44	6693.98	2866.44	517.35	-1229.72
$NDVI^2$	-195.83	595.48	-5194.29	-354.26	-518.72	-490.29
LST_{NR}^2	-42.61	240.13	-641.704	-210.10	-27.92	106.41
Intercept	-7.00	65.44	193.581	24.93	-8.00	-19.82

*LST_{NR} represents normalized land surface temperature

-elkhand some regions witnessed an increase in LST by almost 13°C. While the difference in the LST from 2019 to 2014 decreased in the northern Bundelkhand, but the region too is experiencing a 4°C higher LST. An interesting observation with respect to soil moisture in the region was that while the northern region experienced a soil moisture reduction by almost 2 kgm^{-2}, the southern region had a net addition in the soil moisture content. This behaviour was due to possible moisture recharge by many perennial river confluences in the region. This also signified that sustaining grasslands in the region is not difficult as the soil still carries the moisture in amount needed for the growth and survival of grasslands. In order to assess the soil moisture situation better in terms of spatial visibility, downscaling was being performed.

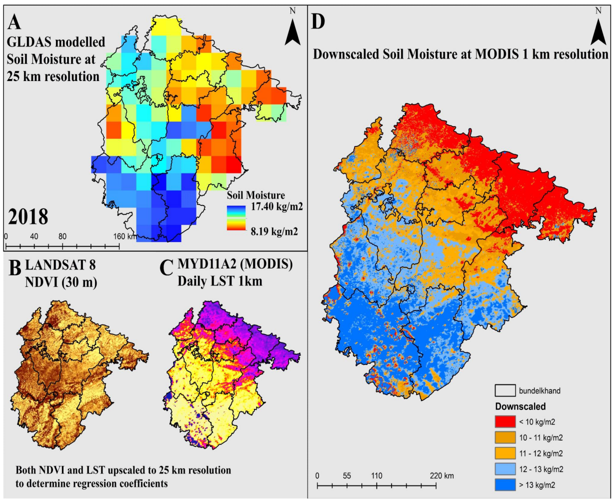

Fig 5. Downscaled soil moisture product derived from GLDAS using MODIS (MYD11A2 – 1 km day LST) and LANDSAT 8 (30 meter rescaled to 1000 meters)

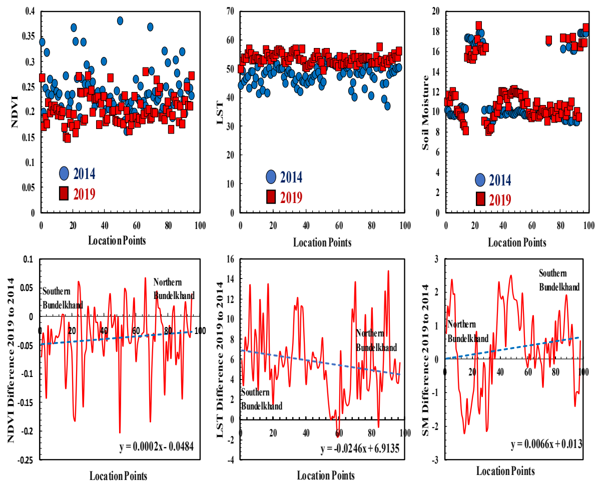

Fig 6. Behaviour of NDVI, LST and soil moisture across the study area from 2019 to 2014

The maximum change in the vegetation cover was in the northern Bundelkhand region in the year 2016 (Fig 2), where there was high reduction in grassland cover in the Datia, Jhansi, Jalaun, Hamirpur and Mahoba district. However, this shock was recovered partly in the year 2017, but the NDVI values were decreased signifying the formation of new grasslands with less in chlorophyll content compared to the grassland before 2016. Districts like Tikamgarh recovered better than other districts in post 2016. In terms of LST, new heat hotspots have been developed in the southern region of the study area. The south western region of Bundelkhand could be characterized as the most heated part with LST reaching upto 54° C (Fig 3). The study showed that while the NDVI was decreased under increased LST from 2019 to 2014, there was strong agglomeration or concentration of NDVI values within the range of 0.15 to 0.25 (Fig 7). This further indicated that grasslands with NDVI value between 0.2 to 0.250 had better adaptability to survive. The results showed that as LST reached 50° C or beyond there was almost elimination of grasslands having NDVI values between 0.250 to 0.3.With respect to soil moisture there were two distinct clusters corresponding to northern and southern Bundelkhand region.The northern Bundelkhand region had lesser soil moisture and a NDVI ranged between 0.15 to 0.250. Because of high LST there was elimination of grasslands having NDVI ranged between 0.25 to 0.3 even with constant soil moisture. In case of southern Bundelkhand region the same phenomenon existed where LST played a dominant role in determining the grasslands health as compared to soil moisture.

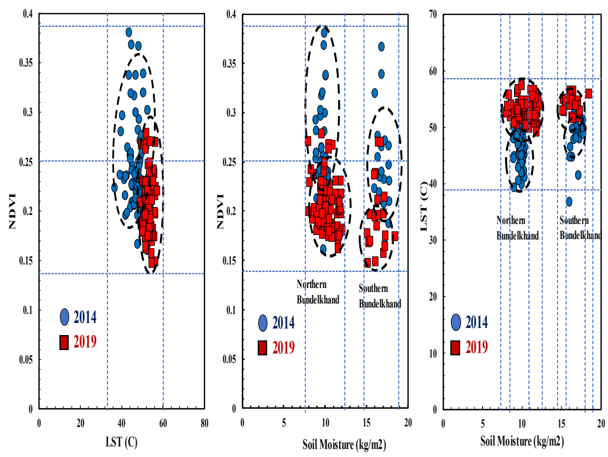

Fig 7. Co-plots of NDVI and LST showed the adaptability of the grasslands with respect to increase in LST. NDVI and soil moisture plot further validated the point that grasslands with NDVI values between 0.2 to 0.250 were more adaptable to survive

Depth varying chemical characteristics of the soil: Depth did not play any role in changing the soil CEC (Fig 8). The average CEC concentration for the Bundelkhand region ranged between 14 to 55 c mol/kg. Usually three clay minerals *i.e*., kaolinite, illite and chlorite exist in this range based on their exchanging power with regards to cations (Ca^{2+}>Mg^{2+}> H^{+}> K^{+}>NH_4^{+}> Na^{+}) (Grim., 1968). The presence of kaolinite ($Al_2Si_2O_5(OH)_4$) denotes in-congruent silicate weathering of sodic plagioclase ($Na(AlSi_3)O_8$), calcic plagioclase ($Ca(Al_2Si_2)O_8$), K-feldspar ($K(AlSi_3)O_8$) and pyroxene under acidic conditions. Usually the concentration of kaolinite in soil peaks when mean rainfall is around 100 cm followed by higher aggregation of bauxite, relating with increasing rainfall. High CEC improves the nutrient holding capacity of the soil. Any sudden change in pH can also be buffered with high CEC. This highlights the fact that even if there was loss of the top soil of the Bundelkhand region due to erosion, the underlying layers were capable enough to hold the nutrients and stabilize the organic complexes essential for sustaining the crop as well as grassland growth. However, soil acidification was the biggest threat for the region as any further decrease in soil pH will negatively impact the CEC of the soil leading to immediate decline in productivity. Spatially and temporally, northern Bundelkhand can be speculated to be experiencing a decline in grassland cover on account of low soil CEC. This brings out a more serious point that grassland growth in the region is directly related to the easily available nutrient from the surface as the soil's nutrient holding capacity itself is very low (CEC ~ < 30 c mol/kg). However, the pH of the northern Bundelkhand lied between 7.5 to 8.0, signifying that lower CEC can increase cationic exchange in the soil system. However, lower pH (~7.0 to 7.5) in the southern Bundelkhand showed that the region may experience drastic changes in the grassland cover if further acidification occurs. Another important observation was the organic richness (soil organic carbon content) of the region decreasing greatly with depth. This signifies that despite having high GPP the sub-surface energy synthesis will be less.

Another major concern for the southern Bundelkhand was the high percentage of clay particles (> 40 %) along with soil pH in the range of 7.0 to 7.5, as it is an optimum condition for the release of geogenic contaminants from the groundwater, given the occurrence of microbial breakdown of the organic matter under the presence of anthropogenically induced nitrate (Singh *et al*., 2020). High surface carbon content (~ 49 to 169 g/kg) makes rainfall led leaching vulnerable to contamination adsorp-tion on to the clay mineral specially kaolinite. The higher soil moisture content in the southern Bundelkhand can also be explained based on higher clay content reaching to almost 50% of the total soil. With SOCC concentrated mostly in the top layer of the soil, it becomes extremely important to conserve the amount of moisture present in this layer.

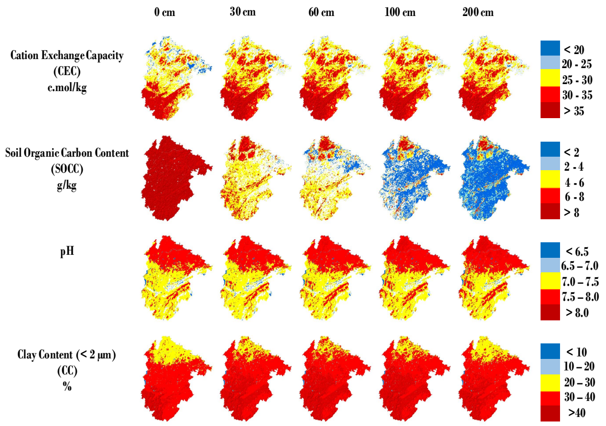

Fig 8. The variations of various chemical parameters of the soil with depth

Conclusion

The study showed that the area under grasslands was declined consistently and significantly and therefore, there would be a net negative stress on the livestock survival in the region. The drastic changes in LST, a phenomenon becoming dominant with reduction in grasslands, is a challenge for the region. While the soil moisture remained intact it only showed that there is ample opportunity in the region to bring up the grassland cover. One of the anthropogenic threats to the overall health of the grasslands could be the excessive grazing done in the region, a point raised by many researchers through scientific literatures in the past. Therefore, a holistic approach must be adopted in limiting the excessive grazing by the livestock so that the day time LST could be limited to below 50° C, a factor found very critical for the health of the grasslands. The nutrient carrying capacity of the soil can severely be deteriorated if no measures are being taken in order to prevent the acidification of the soil system.

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