

Influence of Water Borehole Development on Rangeland Ecosystem Dynamics in Amballo Location, Obbu Ward, Moyale Sub-County, Marsabit County, Kenya

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Abstract

Sustainable management of arid and semi-arid rangelands is essential for maintaining ecosystem health and supporting pastoral livelihoods. This study examined the influence of water infrastructure development on rangeland ecosystem dynamics in the Amballo location of Obbu Ward, Moyale Sub-County, Marsabit County, Kenya. A mixed-methods approach integrating vegetation surveys, remote sensing and household interviews was employed. Vegetation data were collected from transects established near the borehole and a control site, while Landsat imagery from 2000, 2007, and 2020 was used to assess long-term vegetation cover changes. Data were analyzed using descriptive statistics, two-sample t-tests, and the Shannon–Wiener diversity index. The findings showed significant reductions in woody plant density ($p = 0.006$) and herbaceous biomass ($p = 0.013$) near the borehole compared with the control site. Plant diversity was also lower near the water source ($H' = 2.20$) than in the control area ($H' = 2.86$), indicating increased dominance of disturbance-tolerant species. Remote sensing analysis revealed a 16.97% decline in open grassland and a 17.60% increase in bare land between 2000 and 2020, suggesting progressive rangeland degradation. Household responses identified livestock concentration, overgrazing, trampling, tree harvesting, drought, and climate variability as key drivers of vegetation change. The study concludes that while water infrastructure improves water access and support pastoral livelihoods, they also contribute to localized degradation by altering livestock distribution and increasing grazing pressure around water points. Improved grazing management, strategic water point planning and restoration of degraded areas, are recommended to promote sustainable pastoralism.

Keywords: *Sustainable rangelands management, ecosystem resilience, community perception, and rangeland degradation.*

1.0 Introduction

More than 80% of Kenya's land area is classified as arid and semi-arid lands (ASALs), which are characterized by low and variable rainfall, recurrent droughts, and high vulnerability to land degradation and desertification. These areas support approximately 36% of Kenya's population and more than 70% of the country's livestock herd, making them important to national food security, pastoral livelihoods, and rural economies (Food and Agriculture Organization of the United Nations [FAO], 2024). Livestock production is a major economic activity in the ASALs, supporting pastoral and agro-pastoral communities through food, income, employment, and trade (FAO, 2024; Ministry of Agriculture and Livestock Development [MoALD], 2025). However, increasing human and livestock populations, recurrent droughts, land fragmentation, and competing land uses have intensified pressure on rangeland resources, contributing to vegetation degradation, soil erosion, reduced forage availability, and declining ecosystem productivity (United Nations Convention to Combat Desertification [UNCCD], 2022; World Bank, 2022).

Marsabit County is predominantly arid and semi-arid, with pastoralism remaining an important livelihood system. Livestock production depends on the availability and distribution of pasture and water, while livestock mobility helps pastoralists cope with the spatial and temporal variability of dryland resources. However, increasing livestock numbers, recurrent droughts, climate variability, and growing demand for natural resources are placing additional pressure on the county's rangelands. These pressures may contribute to overgrazing, vegetation degradation, soil erosion, and changes in vegetation composition and structure (Intergovernmental Panel on Climate Change [IPCC], 2022).

Water scarcity has encouraged the development of artificial water sources, including boreholes, water pans, and dams, to improve access to water for people and livestock. Although such

infrastructure can support pastoral livelihoods and reduce vulnerability during drought, permanent water sources may also concentrate livestock around water points, increasing grazing and trampling pressure. This can contribute to vegetation degradation, soil compaction, reduced infiltration, and changes in plant community composition. Evidence from northern Botswana shows that artificial water points can influence vegetation dynamics. Mpalo et al. (2024) found significant woodland-cover decline within 10 km of an artificial water point in the Chobe Enclave, with stronger changes occurring closer to the water source. Concentrated livestock activity around permanent water points may also alter soil physical conditions through trampling and compaction, potentially affecting infiltration, erosion, and vegetation productivity (Niamir, 1998; Reed et al., 2007).

However, the ecological consequences of artificial water points vary with local conditions, including livestock density, grazing practices, vegetation characteristics, soil properties, rainfall variability, and livestock mobility. Findings from other dryland regions therefore cannot automatically be generalized to northern Kenya. In Marsabit County, particularly Obbu Ward in Moyale Sub-County, water infrastructure has been developed to improve access to water for pastoral communities and livestock, but permanent water sources may also alter livestock movement and concentrate grazing around water points.

Despite evidence from other dryland ecosystems, limited site-specific research has examined the effects of borehole development on rangeland ecosystem dynamics in Amballo, Obbu Ward. In particular, there is limited empirical evidence integrating vegetation diversity, distribution and productivity with soil physical conditions around boreholes. There is also limited evidence on long-term vegetation-cover changes associated with water development and limited integration of ecological measurements with pastoralists' perceptions of changes in rangeland conditions. This geographical, ecological, temporal, and socio-ecological knowledge gap limits

understanding of how borehole development is influencing rangeland resources in the study area.

This study therefore examines the effects of borehole development on rangeland ecosystem dynamics in Amballo, Obbu Ward, Moyale Sub-County, Marsabit County, Kenya. It assesses vegetation diversity, distribution and productivity; soil physical conditions; changes in vegetation cover over time; and pastoralists' perceptions of the implications of borehole development for rangeland conditions. The findings are expected to provide locally relevant evidence to support sustainable water-infrastructure planning and rangeland management in northern Kenya.

“The study found substantial differences in vegetation condition between the borehole-influenced and comparison areas of Amballo”

Problem Statement

Sustainable management of arid and semi-arid rangelands requires balancing ecological integrity with pastoral livelihoods. Healthy rangelands should maintain vegetation productivity, soil condition, and adequate forage while supporting livestock production and mobility (Behnke & Scoones, 1993; Fernández-Giménez, 2000). Boreholes improve water access for pastoral communities and livestock, particularly during dry periods, but may concentrate livestock around water points, increasing grazing and trampling pressure and potentially altering vegetation and soil conditions (Reed et al., 2009).

In Amballo location, Obbu Ward, limited empirical evidence exists on the effects of borehole development on vegetation diversity, productivity, soil physical conditions, and long-term vegetation-cover change. There is also

limited integration of ecological evidence with pastoralists' perceptions. This study therefore assesses the effects of borehole development on rangeland ecosystem dynamics to provide evidence for sustainable water development and rangeland management.

Objective of the study

The overall objective of the study was to determine the influence of water infrastructure development on rangeland ecosystem dynamics in Amballo location, Obbu Ward, Moyale Sub-County, Marsabit County.

The specific objectives were to:

- a) To assess the influence of borehole development on vegetation diversity, distribution, and productivity in Amballo location, Obbu Ward, Moyale Sub-County, Marsabit County.
- b) To assess pastoralists' perceptions of the implications of borehole development on rangeland conditions in Amballo location, Obbu Ward, Moyale Sub-County, Marsabit County.
- c) To evaluate changes in vegetation cover over time in relation to borehole development in Amballo location, Obbu Ward, Moyale Sub-County, Marsabit County.

2.0 Materials and Methods

Study Area and Research Design

The study was conducted in Amballo location, Obbu Ward, Moyale Sub-County, Marsabit County, Kenya, an arid and semi-arid area where pastoralism is the main livelihood. The landscape is characterized by Acacia-dominated woodlands, shrublands, and open grasslands and experiences recurrent droughts and variable rainfall. A mixed-methods research design integrating vegetation field surveys, remote sensing, and household interviews was adopted to assess the influence of borehole development on rangeland ecosystem dynamics.

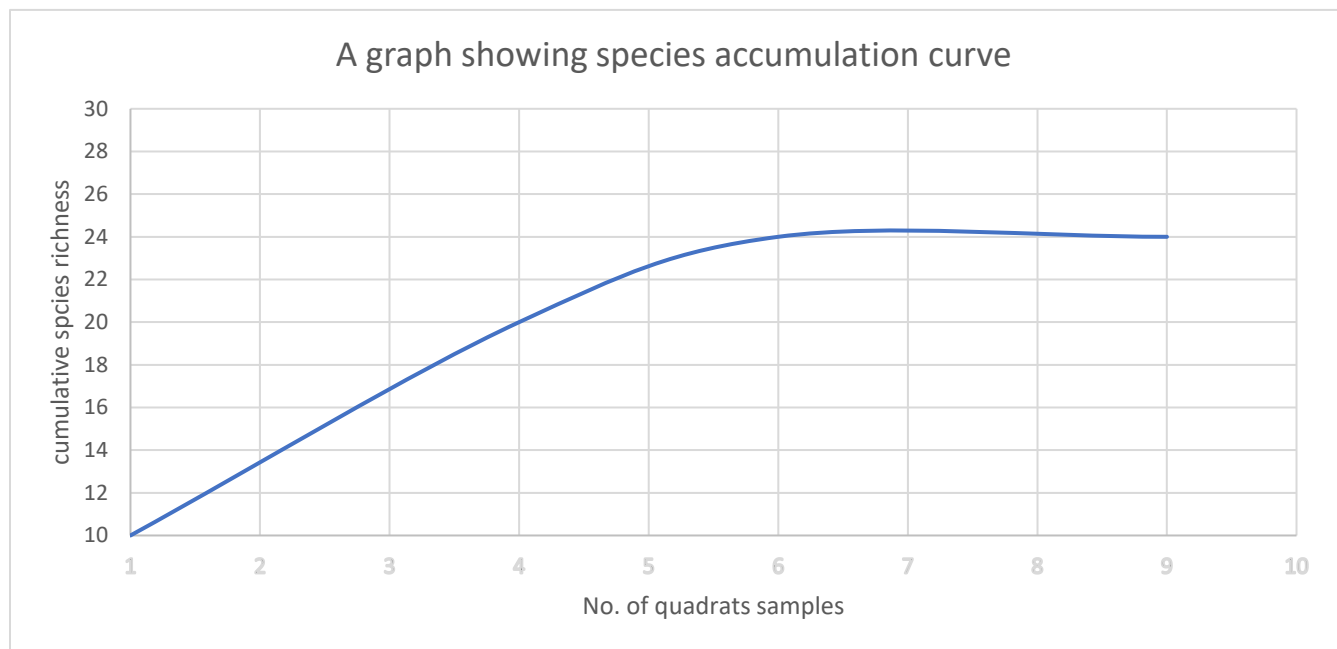
Methods and procedures of data collection

1-km transects were established to provide a comparative assessment of vegetation conditions. The first transect was established in the borehole-influenced area, while the second was located approximately 8 km from the borehole and served as a comparison transect. Each transect contained 20 sampling points at 50-m intervals. Woody vegetation was assessed using the Point-Centered Quarter (PCQ) method (Cottam & Curtis, 1956).

At each point, the nearest woody plant in each of four quadrants was identified, and species, distance, height, DBH, and developmental stage were recorded. Herbaceous vegetation was assessed using 1×1 m quadrats positioned approximately 1 m from sampling points. Species composition, richness, percentage cover, and above-ground biomass were recorded. Species accumulation curves were used to assess sampling adequacy.

Figure 1

Species accumulation curve



The household target population comprised approximately 100 households. The sample size was determined using Yamane's formula:

$$n = N / [1 + N(e)^2]$$

where n is the sample size, N is the target population, and e is the margin of error. A 15% margin of error was adopted because of logistical and resource constraints associated with conducting interviews in the remote pastoral setting:

$$n = 100 / [1 + 100(0.15)^2] = 30.77 \approx 31$$

30 households were selected from 15 settlement clusters, with two households randomly selected from each cluster.

For remote sensing, Landsat satellite imagery covering 2000–2020 was used to assess long-term vegetation-cover dynamics. The year 2007, when the borehole was established, was used as the intervention point. The analysis therefore divided the time series into a pre-borehole period (2000–2007) and a post-borehole period (2007–2020). Images from comparable periods of the year were selected to minimize seasonal effects, and cloud and cloud-shadow pixels were removed before analysis. Vegetation condition was assessed using

the Normalized Difference Vegetation Index (NDVI): $NDVI = (NIR - Red) / (NIR + Red)$

Appropriate red and near-infrared bands were used for each Landsat sensor. Annual NDVI composites were generated to examine temporal trends in vegetation condition and spatial differences between the borehole-influenced and comparison areas. GIS was used to map and quantify changes in vegetation cover, while NDVI trends for the pre- and post-borehole periods were compared to assess changes associated with borehole development.

Data Analysis

The data was analyzed using both descriptive and inferential statistical methods. To visualize the results, frequency distribution tables and bar charts were used. A two-sample t-test was used to analyze significant differences in the various parameters between the two study sites. Additionally, the Shannon–Wiener diversity index (H') was also used to determine existence of species richness and diversity. (Shannon & Weaver, 1949).

Ethical considerations

Ethical considerations were observed throughout the study to ensure that the research was conducted responsibly and with respect for the rights, dignity, and welfare of all participants. Prior to data collection, ethical approval was obtained from the relevant university authorities, while a research permit was secured from the National Commission for Science, Technology and Innovation (NACOSTI). Permission to conduct the study was also sought from the Marsabit County Government, Moyale Sub-County administration, and local leaders in Obbu

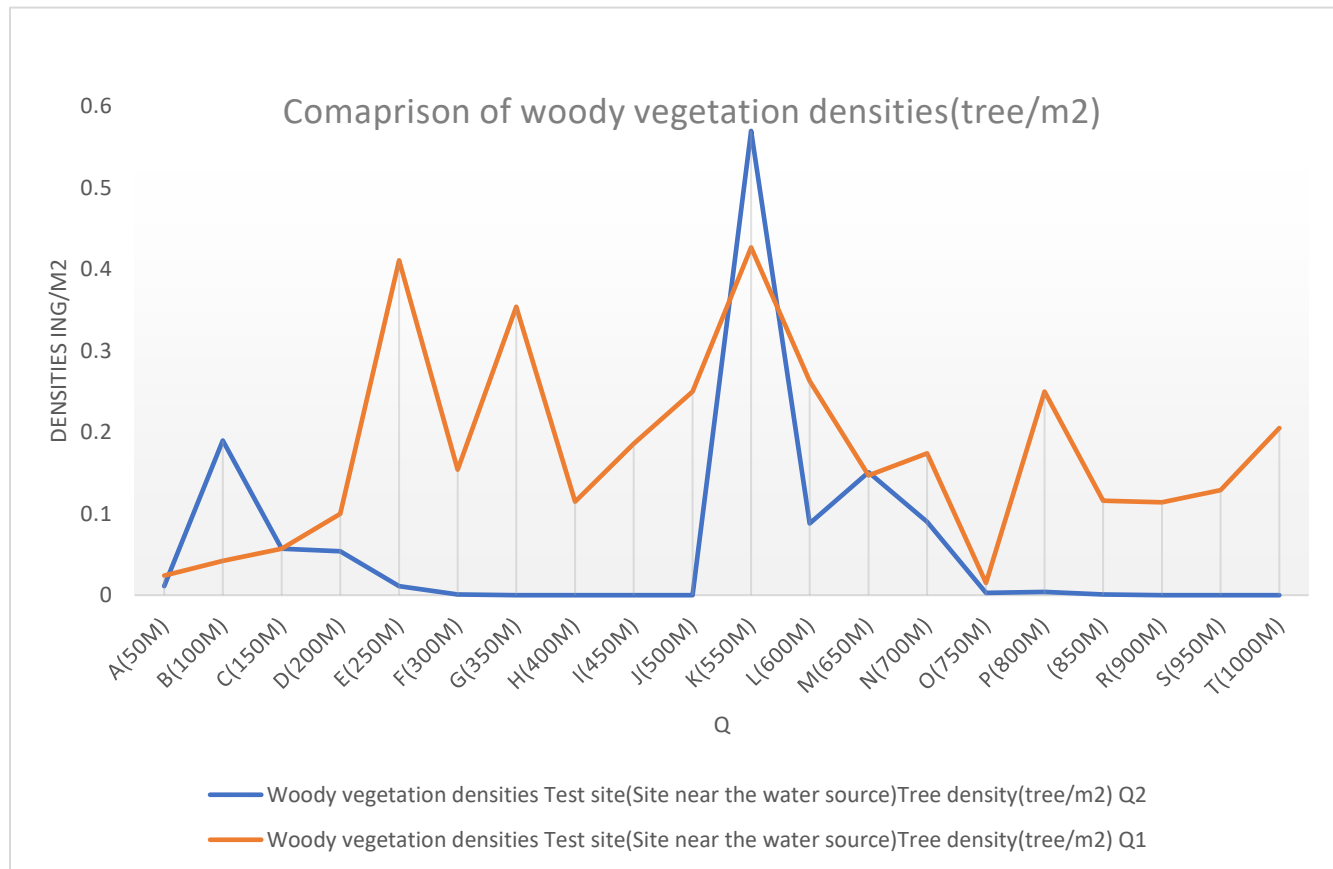
Ward before field activities commenced. Participation in the household survey was entirely voluntary. Before administering the questionnaires, the purpose and objectives of the study were clearly explained to all respondents, and informed consent was obtained from each participant.

3.0 Results and Discussion

Effect of water infrastructure (Borehole) development on Woody Vegetation

The tree densities were measured using PCQ vegetation sampling method in both the control transect and the transect near the borehole. The woody plant density results show that vegetation structure differed between the area near the water source (Q2) and the control site away from the water source (Q1). Tree density near the water source ranged from 0 to 0.570 trees m^{-2} , with several points recording zero woody plants, particularly between 350–500 m and 900–1000 m, indicating sparse and fragmented woody vegetation. Although Q2 recorded a peak density of 0.570 trees m^{-2} at 550 m, this was an isolated case. In comparison, the control site maintained woody plants across all sampling points, with densities ranging from 0.015 to 0.427 trees m^{-2} and higher values recorded at 250 m (0.411 trees m^{-2}), 350 m (0.354 trees m^{-2}), and 550 m (0.427 trees m^{-2}). Overall, the findings indicate that woody vegetation was more persistent and evenly distributed away from the water source, while reduced and irregular densities near the water point suggest increased disturbance, likely associated with concentrated livestock grazing, browsing, and trampling around the water source. Figure 2 below shows comparison between the two sites;

Figure 2
Comparison of woody vegetation densities.



The data were analyzed using two-sample *t*-test assuming unequal variances which showed that tree densities differed significantly between the two transects ($p = 0.006$). The control site recorded a mean tree density of 0.177 trees/m², compared to 0.062 trees/m² near the borehole, indicating that woody vegetation was almost three times denser away from the permanent water source.

The result above brings out the fact that water infrastructure (borehole) has negatively influenced woody vegetation growth and development mainly through Continuous browsing and disturbance which prevent natural regeneration. This led to lower woody plant density close to the water point. Similar condition has also been reported in many other arid and semi-arid rangelands where grazing pressure decreases with increasing distance from watering points (Lange, 1969; Andrew, 1988; Todd, 2006).

Areas farther from the borehole experienced lower grazing pressure, allowing woody vegetation to regenerate and maintain higher densities.

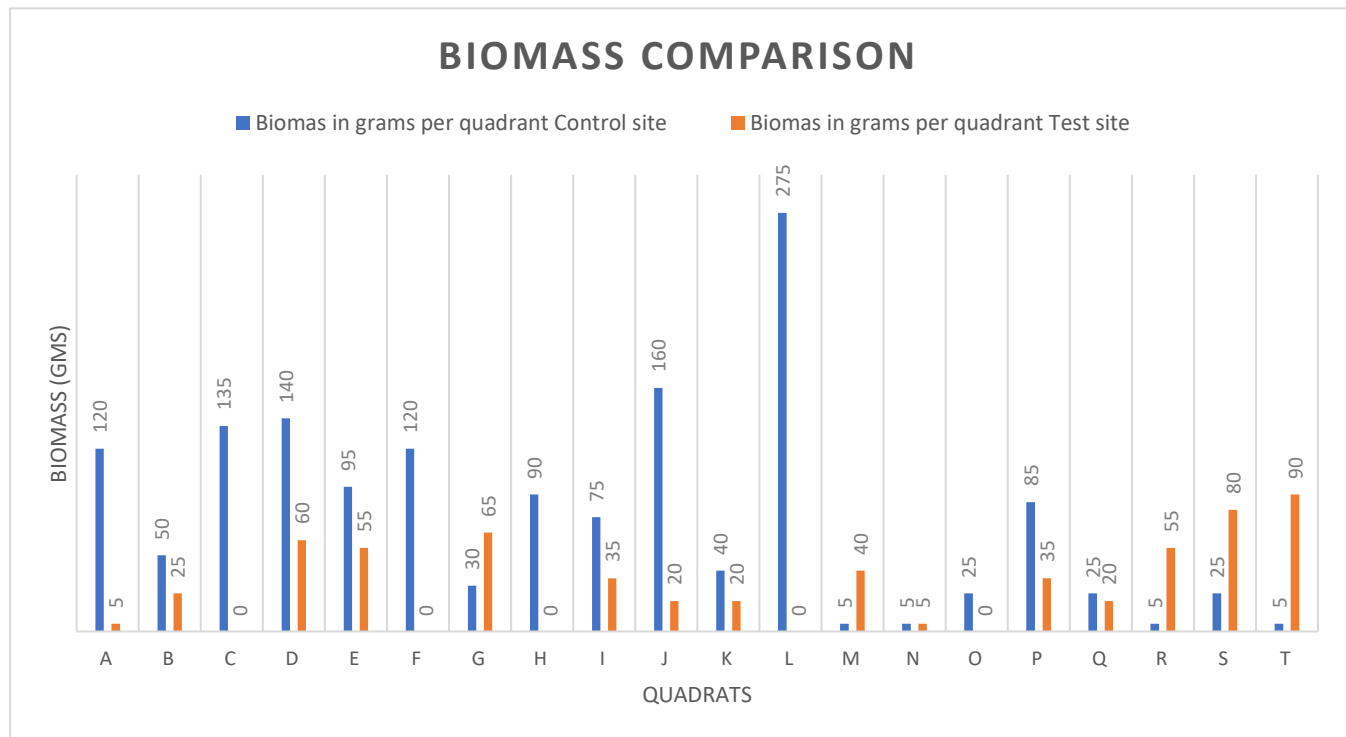
Effect of water infrastructure (borehole) Development on Herbaceous Biomass

The herbaceous plant biomass was sampled using quadrant method where biomass of herbaceous species in each quadrat was recoded for both control site and the site near borehole. Herbaceous biomass differed considerably between the control and test sites, with the control site recording higher biomass values than the area near the water source. The control site biomass ranged from 5 to 275g whereas the test site ranged from 0 to 90 g. The control site recorded the highest biomass values at sampling points with 275 g, 160 g, and 140 g, while the test site had several locations with 0g biomass, indicating reduced vegetation production. Overall, biomass

in the control site was more than twice that of the test site, showing that areas near the water source experienced reduced herbaceous vegetation productivity, likely due to increased livestock grazing pressure, trampling, and repeated use around the water point.

Statistical analysis using a two-sample *t*-test indicated a significant reduction in biomass near the borehole ($p = 0.013$). The control site recorded a mean biomass of 75.5 g per quadrat, whereas the borehole site averaged only 30.5 g per quadrat as shown in figure 3 below;

Figure 3
Vegetation biomass comparison.



Continuous utilization limits vegetation recovery and selectively removes palatable grasses and other herbaceous species, resulting in lower productivity. Bare patches observed near the borehole further increase soil vulnerability to erosion, accelerating degradation processes. Other studies also confirm these findings where substantial reductions in herbaceous biomass around watering points in African savannas was reported (Smet & Ward, 2005; Todd, 2006).

Effect of water infrastructure development (Borehole) on Plant Diversity and richness

Plant species composition also differed between the two sampling sites. The borehole site was dominated by *Vachellia seyal* (28.2%) and *Cordia sinensis* (24.3%), indicating high dominance by a few disturbance-tolerant species. In contrast, the control site exhibited a more balanced distribution of species with greater richness and evenness. Several species, including *Grewia tenax*, *Vachellia reficiens*, *Dobera glabra*, and *Calotropis procera*, occurred only in the control area, while a few disturbance-associated species such as *Eragrostis cilianensis* were recorded only near the borehole as shown in Table 1 below

Table 1

Species composition in the two sites

Species	Local name	%Composition in Areas close to water source	%Composition in control area away from water source
<i>Eragrostis cilianensis</i>	Arda	2.2	0
<i>Cynodon doctylon</i>	Sardo	3.5	9.2
<i>Chrysopogon auheri</i>	Alaloo	2.4	0.9
<i>Panicum maxicum</i>	Loloqa	2.4	1.8
<i>Digitaria naghellensis</i>	Ilmogori	5.9	5.5
<i>Aristida Kenyensis</i>	Matgudes	0	2.5
<i>Dijitaria milanjiana</i>	Iddo	3.5	4.5
<i>Grewia tenax</i>	Deka	0	11.8
<i>Commiphora holtziana</i>	Hagarsu	3.5	7.3
<i>Vachellia reficiens</i>	Sigirso	0	1.8
<i>Cordia Sinensis</i>	Mader	24.3	14.5
<i>Lannea triphyrra</i>	Andarak	0	1.8
<i>Albizia amara</i>	Boria	0	0.9
<i>Boscia coriacea</i>	Qalqach	8.2	2.7
<i>Terminalia orbicularis</i>	Bisiq	0	2.7
<i>Senegalia brevispica</i>	Ames	2.4	0.9
<i>Senegalia melifera</i>	Sapans	0	3.6
<i>Vachellia Paoli</i>	Chachane	1.2	7.3
<i>Commelina africana</i>	Qayyo	0	0.9
<i>Dobera Glabra</i>	Garse	0	3.6
<i>Calotropis Procera</i>	Wara	0	1.8
<i>Caesalpinia trothae</i>	Gorgor	0	1.8
<i>Vachellia Seyal</i>	Wachu	29.5	4.6
<i>Vachellia tortilis</i>	Dadacha	4.7	6.4
<i>Commiphora myrrha</i>	Qumbi	1.2	3.7
<i>Erythrina melanacantha</i>	Sibilichu	1.2	0
<i>Terminalia prunoides</i>	Qorobo	3.5	0

The finding was further confirmed by the Shannon–Wiener diversity index which revealed higher vegetation diversity in the control area ($H' = 2.86$) compared with areas close to the water source ($H' = 2.20$). Similarly, species evenness was higher in the control area ($J' = 0.90$) than near the water source ($J' = 0.79$), suggesting that vegetation communities away from water points were more diverse and evenly distributed.

The differences in plant species composition and diversity between the borehole and control sites indicate that permanent water sources influence

vegetation The dominance of *Vachellia seyal* and *Cordia sinensis* near the borehole, together with the presence of the disturbance-tolerant *Eragrostis cilianensis*, suggests that grazing pressure favors a few resilient species while reducing more sensitive ones. In contrast, the control area supported greater species richness and a more even distribution of vegetation, as reflected by its higher Shannon–Wiener diversity index ($H' = 2.86$) and evenness ($J' = 0.90$). These findings are consistent with previous studies showing that livestock concentration around

permanent water points reduces plant diversity and promotes disturbance-tolerant species, leading to simplified vegetation communities (Andrew, 1988; Thrash & Derry, 1999; Fuhlendorf & Engle, 2001).

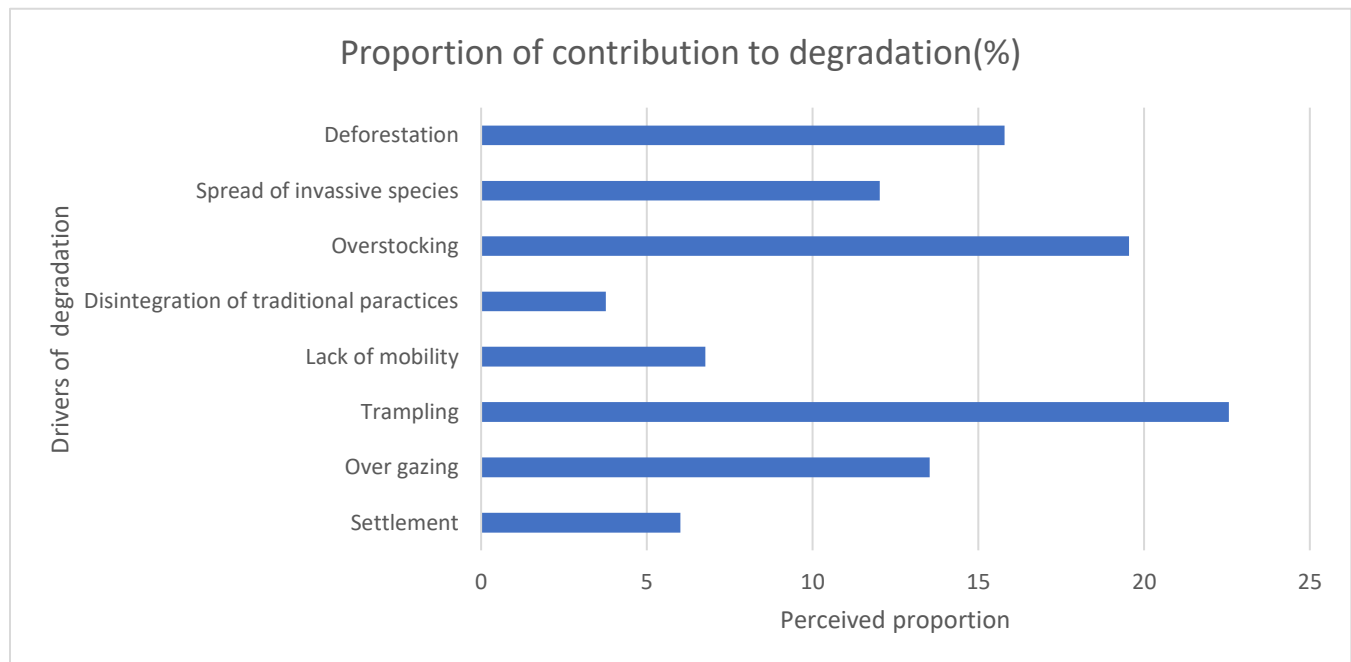
Pastoralists' Perceptions of Vegetation Change

Pastoralists perceived a general increase in woody vegetation and a decline in herbaceous vegetation in the Amballo rangelands. More than 40% of respondents associated the onset of bush encroachment with the *gada* Gobbaa Bulee period (1968–1976), while 27% associated it with Jiloo Aagaa (1976–1984), 22% with Boruu Madhaa

(1992–2000), and 10% with Boruu Guyyoo (1984–1992). *Commiphora africana* was identified as the most rapidly increasing woody species (46.7%), followed by *Vachellia reficiens* (26.7%). Among herbaceous species, *Eragrostis cilianensis* was perceived to be increasing (30%), whereas *Cenchrus ciliaris* (66.7%) and *Chrysopogon auheri* (63.3%) were among the most rapidly declining grasses. Respondents attributed vegetation degradation mainly to livestock concentration, trampling, overstocking, overgrazing, and deforestation. Figure 4 below shows key degradation drivers and levels of effect as perceived by the community

Figure 4

Factors contributing to degradation



Respondents further observed that the borehole attracts livestock from neighboring areas of Marsabit, Wajir County, and southern Ethiopia, increasing grazing pressure beyond the local carrying capacity. Tree harvesting for fuelwood, fencing materials, and livestock enclosures was also identified as an additional driver of vegetation degradation. These community views support ecological theory, which suggests that sustained grazing pressure can drive rangelands from productive grass-dominated communities to

shrub-dominated states through the selective removal of palatable grasses and reduced vegetation recovery. When combined with increasing livestock numbers and intensified human exploitation of natural resources, prolonged grazing pressure accelerates vegetation degradation, reduces ecosystem resilience, and promotes land degradation in arid and semi-arid rangelands (Westoby et al., 1989; Briske et al., 2005; Archer et al., 2017).

Vegetation Change Between 2000 and 2020 in Amballo location.

Remote sensing analysis demonstrated substantial land-cover change during the twenty-year study period. Open grassland declined from 6,723.82 acres in 2000 to 5,582.87 acres in 2020, representing a total loss of 1,140.95 acres (16.97%). Most of this decline occurred between 2007 and 2020, indicating accelerated degradation following establishment of the borehole.

Bareland expanded continuously from 7,008.88 acres in 2000 to 8,242.76 acres in 2020,

representing an increase of 1,233.88 acres (17.60%). The greatest increase also occurred after 2007, reflecting increasing exposure of soil surfaces and declining vegetation cover.

Wooded grassland initially increased between 2000 and 2007, suggesting temporary woody encroachment into grasslands, before declining to 5,281.79 acres by 2020. This pattern indicates that prolonged ecological stress eventually affected both woody and herbaceous vegetation. Below images show vegetation change overtime;

Figure 5

Images showing periodic vegetation changes

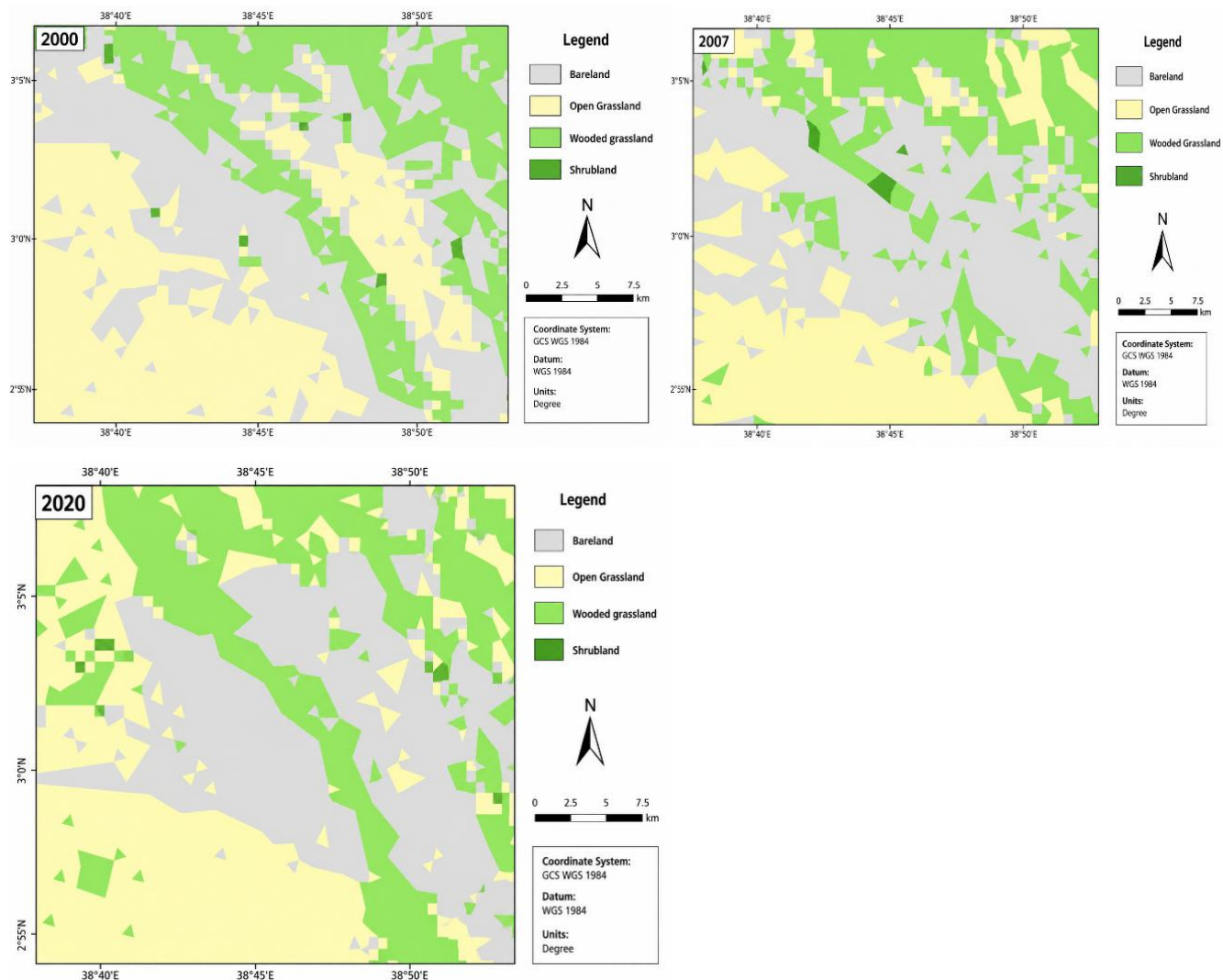


Figure 6

Rate of vegetation change 2000-2007, 2007-2020

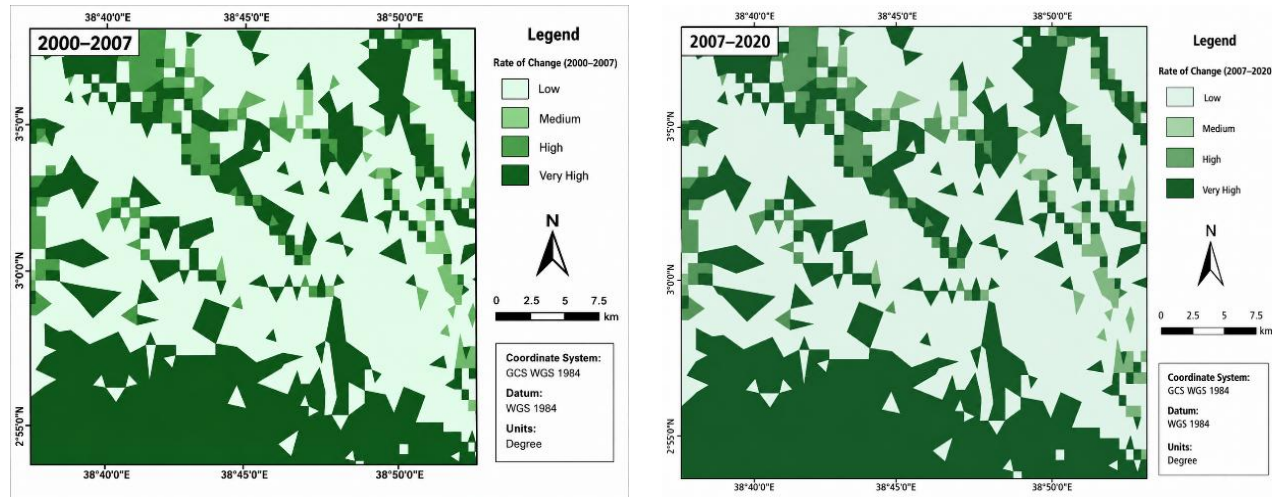


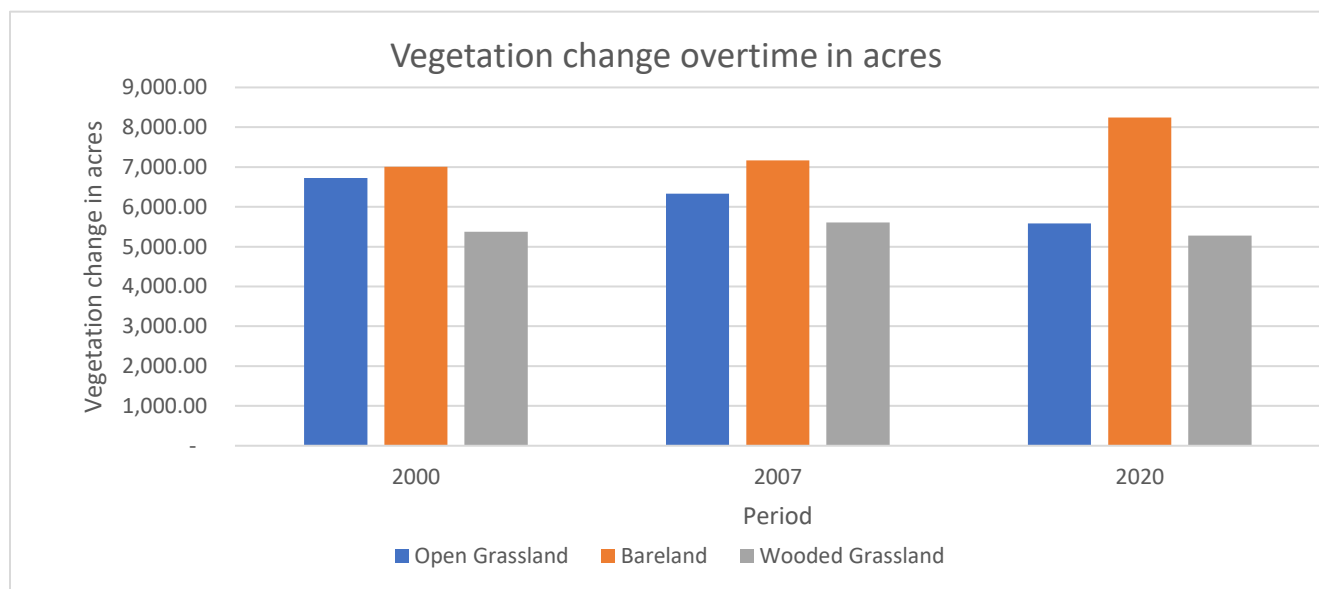
Table 2

Change in three vegetation parameters in acres overtime

Area in ACRES			
Lulc	2000	2007	2020
Open Grassland	6,723.82	6333.29	5582.87
Bareland	7,008.88	7166.19	8242.76
Wooded Grassland	5,374.71	5607.93	5281.79
Total	19,107.41	19,107.41	19,107.42

Figure 7

Graphical presentation of the vegetation change



Although borehole development contributed to vegetation decline was also influenced by

recurrent droughts, rainfall variability, increasing livestock populations, and climate change. The

interaction of these factors accelerated the development of piospheres and intensified rangeland degradation across the study area (Andrew, 1988; Vetter, 2005; IPCC, 2022)

Summary of the findings

Water infrastructure development in rangeland areas has greatly improved water availability for pastoral communities but has also altered vegetation dynamics by encouraging livestock to remain around permanent water sources as well as emergence of settlement in those areas. The concentration of grazing near water sources has contributed to reduced the presence of palatable grasses, increased the dominance of grazing-tolerant shrubs and woody species, and lowered vegetation diversity. These findings are supported by field observations showing lower species diversity and evenness near boreholes than in control areas, reflecting the formation of piospheres where grazing pressure is most intense (Andrew, 1988; Thrash & Derry, 1999; Fuhlendorf & Engle, 2001).

However, borehole development is only one of several factors driving vegetation change in the Amballo rangelands. Recurrent droughts, erratic rainfall, increasing livestock numbers, and climate change have further reduced vegetation recovery and accelerated land degradation. The combined influence of these factors has simplified plant communities, reduced ecosystem resilience. These results agree with previous studies that identify grazing concentration, climate variability, and changing land-use practices as major drivers of rangeland degradation in arid and semi-arid ecosystems (Vetter, 2005; Briske et al., 2005; IPCC, 2022).

4.0 Conclusion

The study found substantial differences in vegetation condition between the borehole-influenced and comparison areas of Amballo. Woody plant density, herbaceous biomass, plant diversity and species evenness were generally lower near the borehole, while remote-sensing

analysis showed a decline in open grassland and an expansion of bare land between 2000 and 2020. Household perceptions similarly identified livestock concentration, overgrazing, trampling, tree harvesting and climatic variability as important drivers of rangeland change. These findings suggest that borehole development is associated with localized changes in vegetation condition, particularly through the concentration of livestock around permanent water sources. However, the observed changes cannot be attributed to the borehole alone because drought, rainfall variability, livestock population changes and other land-use pressures may also have contributed. Sustainable water-point planning, rotational grazing, controlled livestock concentration and restoration of degraded areas are therefore important for maintaining rangeland productivity and resilience.

5.0 Recommendations

1. **Strategic water-point planning:** Future boreholes should be strategically located and planned alongside grazing-management measures to reduce excessive livestock concentration around permanent water sources.
2. **Strengthening community grazing management:** Community-based grazing systems should be strengthened to regulate livestock concentration and allow degraded areas near water points to recover.
3. **Restoration of degraded areas:** Areas showing severe vegetation loss and bare-soil expansion should be prioritized for rangeland restoration and reseeding with locally appropriate native forage species.
4. **Integration of pastoral knowledge:** Local pastoralists should be actively involved in water-point planning and rangeland management because their knowledge of grazing patterns, drought responses and vegetation changes can complement scientific monitoring.

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