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Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems

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Preface

Political and economic transformations, increasing populations, globalization, and climatic changes in the drylands of Greater Central Asia, which have been occurring over the past decades, have greatly affected the *people, societies, and ecosystems* of the region. Central Asia has experienced many drastic changes in land use from the Virgin Lands Campaign in mid-1950s to the abandonment of agricultural fields after the breakup of the Soviet Union in 1991 to their recultivation in more recent years. These and other changes over Greater Central Asia affected the environment and societies of the region, where water use by humans and water availability for crops, livestock, and other human uses have been the primary drivers of environmental changes. The most well-known (and analyzed) example in the region is the decades-long desiccation of the Aral Sea resulting from the diversion of two rivers for crop irrigation, specifically to increase cotton yields and combat soil salinization. Satellite observations that have accumulated during the last five decades provide a rich time series of the dynamic land surface, enabling systematic analysis of changes in land cover and land use from space. In the case of Aral Sea, Landsat satellite observations have allowed the continuous monitoring of its dynamics at spatial resolutions of tens of meters since early 1970s.

The breakup of the Soviet Union had huge impact on the structure of the society, local and regional economies, and the way people use the land. In some countries, state-owned and collectivized farms were transitioned to privately owned fields and enterprises. Some arable lands were abandoned, others idled or continued with cultivation; there were substantial changes in what was being produced and to whom it was being marketed. Space observations of nightlights, for example, have revealed that many cities and towns experienced significant shifts in population—both increasing and decreasing depending on country and region. During the economic boom in China that followed its accession to the World Trade Organization in 2001, the northwest drylands have experienced strong rural-to-urban migration, along with a dramatic expansion of urban infrastructure, while populations more than tripled.

This book describes and analyzes various patterns, processes, and consequences to the population and landscapes of the Greater Central Asia region. It is a compilation of results from studies on land-cover and land-use changes and their interactions with carbon, water and energy cycles, landscape dynamics, the role of institutional changes, as well as the consequences of global changes. The book is a truly interdisciplinary collaborative effort by an international team consisting of scholars from the USA, Europe, Central Asia, and elsewhere, under the auspices of the Northern Eurasia Earth Science Partnership Initiative (NEESPI) supported primarily by the NASA Land-Cover/Land-Use Change Program. It is of interest and directed to a broad range of scientists within natural and social sciences, those involved in studying recent and ongoing changes in drylands, be they senior scientists, early career scientists, or students. These studies provide the analysis of the dramatic changes in land uses triggered by an abrupt change in the economies of the region and land management. Lessons learned from these studies are additional evidence for the sustainability development of the drylands. The satellite data used for these studies were mostly from NASA and ESA optical sensors with coarse (~5 km to 250 m) and medium (100 m to 10 m) spatial resolutions.

In the context of the forthcoming Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) the IPCC Special report on Climate Change and Land published in 2019 provides a broad overview of the situation of Greater Central Asia.

In particular, the present book can help answer questions on the perception of risks and benefits of climate change, adaptation and mitigation options, and societal responses, including sociological aspects.

We warmly thank all the contributors of this book and acknowledge NASA's support. We also appreciate several colleagues for their constructive peer review of the drafts of the chapters. We thank Connor Crank for creating the webpage to facilitate communication among the authors and Kaylee Peterson for checking the format of all the chapters.

Washington, DC, USA Garik Gutman
January 2019

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Chapter 8
Hydrology and Erosion Risk Parameters for Grasslands in Central Asia

Kenneth E. Spaeth, Mark A. Weltz, D. Phillip Guertin, Jiaguo Qi, Geoffrey M. Henebry, Jason Nesbit, Tlektes I. Yespolov, and Marat Beksultanov

8.1 Introduction

The Republic of Kazakhstan, located in the center of the Eurasia is the ninth largest country in the world (2.7 million km^2) and was the second largest republic in the former Soviet Union. The land area of Kazakhstan extends about 3000 km from the Caspian Sea to the Altai Mountains on the eastern fringe, and 1600 km from the western-Siberian lowlands to the Tianshan Mountains on the southern border. Four major ecoregions are represented in Kazakhstan: steppe (25% of land area),

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semidesert (25%), desert (40%), and mountains (7%) (Ryabushkina et al. 2008). Kazakhstan ranks as the fifth largest country in terms of range and pastureland. The area of focus on this paper is the Kazakh steppe (also known as the Kirghiz steppe), a vast temperate grassland with interspaced savannas and shrublands in northern Kazakhstan (Fig. 8.1). It is the largest region of dry steppe rangeland and covers approximately 804,500 km^2. Historically, nomadic herders used the Kazakh steppe for grazing animals. While Kazakhstan was part of the Soviet Union, about 40% of the land area was cultivated (the *Virgin Lands* program) after 1950 (Schillhorn-van-Veen et al. 2003). During this time, the nomadic life style began to be replaced by collective state managed farms (kolkhoz). During the 1950s and 1960s, significant wind and water erosion degraded many of these cultivated areas, many of which were largely abandoned by the 1990s following independence. Today, the Kazakh steppe is fragmented with a mosaic of different land uses.

After independence from the Soviet Union at the end of 1991, several laws were enacted in Kazakhstan to regulate land use and ownership, mostly arable lands, but some of these laws have been applied to range and pasturelands. However, there is apparently minimal specific oversight as to management of special issues specific to

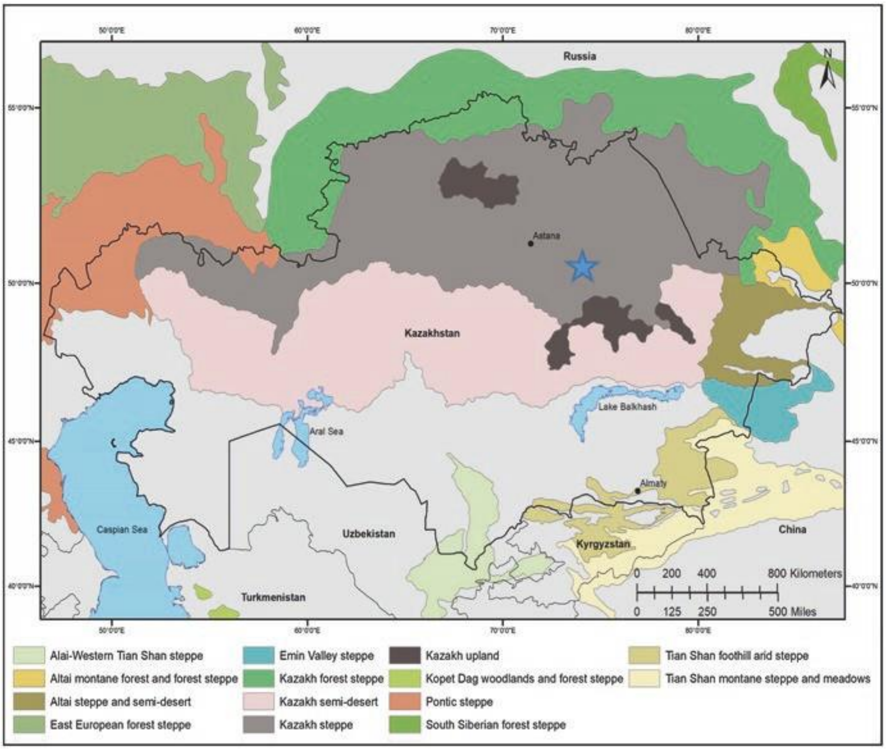

Fig. 8.1 Map of major steppe biomes in Central Asia. Blue star designates location of Yntaly, in the Karagandy Province, Kazakhstan

rangelands – Schillhorn-van-Veen et al. (2003) state that: "Consequently, the rangeland resources are currently used without proper regulation or oversight. The new Land Code (2003) allows private ownership of arable land as well as for much of the rangeland [today the majority of the rangeland is non-private] … the Government is facing the question of institutional oversight of the property both privately and state owned to assure its long-turn efficient use from ecological and economic points of view [the Land Law 2003 recognizes some lands used traditionally for grazing and classifies about 17 million ha as commons]".

Large tracts of rangeland still remain in government control and ownership with various estimates of rangeland degradation: 60% of Kazakhstan's arid areas (desert zone), or 30% of the pastureland are degraded due to overgrazing (Kharin et al. 1986). Schillhorn-van-Veen et al. (2003) estimated that 30–40% of the Nations rangeland were degraded. Robinson et al. (2003) concluded that these estimates are probably lower since the independence of Kazakhstan as livestock numbers had decreased significantly since gaining independence. They estimated that the range was in good condition overall. Robinson et al. (2003) stated that there is a void in the literature regarding Kazakhstan's rangeland. At present, the Government is aware of the repercussions of past land policies and is concerned with land degradation and restoration activities as well as how these lands are managed into the future. Without national level information of rangeland conditions, it is challenging to devise effective policies on rangeland management and planning. The Kazakh Ministry of Agriculture is focused on the well-being of its rangeland resources for long-term sustainability with increased conservation management focused on restoration, extended livestock production, and international markets (*cf*. Qi et al. 2020, Chap. 5). Climate change is also playing a key role in the land management and rangeland grazing potentials. Given the ongoing changes in regional climate change, especially the warming trend (*cf*. Henebry et al. 2020, Chap. 3) and changing precipitation patterns (*cf*. Groisman et al. 2020, Chap. 2), the Kazakh government has issued a number of adaptation policies to cope with water stress. These policies and potentially increasing uncertainties in agriculture, particularly crops and pastures, may further result in agricultural abandonment and land use conversion to grazing lands (*cf*. Qi et al. 2020, Chap. 5; Kappas et al. 2020, Chap. 9). Yet there is no national level source of rangeland health/condition information for future land use planning, due to the lack of technical capabilities for holistic rangeland assessments.

Throughout the world, rangelands are dynamic and commonly influenced by many different perturbations, natural and anthropogenic, which influence rangeland ecosystem function over a wide range of spatial and temporal scales (Williams et al. 2016). Climatic extremes such as drought and periods of intermittent above average precipitation can have profound influences on vegetation composition and biotic integrity, soil nutrient fluxes, soil surface stability, and hydrology and erosion processes. Considering climate extremes with other disturbances such as natural (*e.g.*, insect and plant diseases), wildfire, and diversity of grazing practices, the matrix of influencing factors on rangeland community functions becomes quite complex. In addition to vegetation composition changes, runoff and soil loss are effective quantitative indicators of current management impacts (Weltz and Spaeth 2012).

These hydrologic indicators have been used to infer impacts of vegetation changes due to grazing and drought on water availability and quality, forage availability for domestic livestock and/or wildlife, which ultimately influence the protective capacity of sustainability of the plant community (Weltz and Spaeth 2012; Williams et al. 2016; Hernandez et al. 2017). In this chapter, we examine potential hydrologic and water erosion dynamics on vegetation class 38 of the Atlas of Kazakhstan (2014), Kazakh steppe (*Stipa capillata, Festuca valesiaca, Artemisia frigida, and A. schrenkiana*) with several vegetation state changes. Our objective is to introduce a hydrology and erosion modeling method for holistic rangeland assessment to demonstrate feasibility and usefulness of this technology for rangeland management decision making.

8.2 Methods

8.2.1 Study Area

The Kazakh steppe is representative of a semi-arid, continental climate, and average precipitation ranges from 200 to 400 mm from south to north. Average temperatures range from 20 to 26 °C in July to −12 °C to −18 °C in January. The flora of the Kazakhstan is diverse, with over 13,000 species, of which 5754 are vascular plants (Ministry of Environmental Protection 2009). In the National Atlas of the Republic of Kazakhstan, there are 23 represented plant community associations for the dry temperate dry steppes and dry steppes on chestnut soils, which dominate the Kazakh steppe. The site for this study was near Yntaly, in the Karagandy Province, Kazakhstan (Fig. 8.1). The site is vegetation classification 38, Kazakh steppe (*Stipa capillata, Festuca valesiaca*, *Artemisia frigida, and A. schrenkiana*) (Atlas of Kazakhstan 2014) (Fig. 8.2). According to the United States system of soil nomenclature, on-site classification was a mollisol with a silty clay loam texture.

8.2.2 Data and Methods

At each study site, slope, aspect, vegetation classification, five clip quadrats for production estimates, brief description of soil profile with surface soil texture identification, and rangeland health assessment (Pellant et al. 2020) were made. Plant species foliar cover and ground cover parameters were determined from a 0.16 m^2 macroplot consisting of two 45.7 m transects aligned north to south and east to west (Table 8.1). The line point intercept method was used at every 0.9 m along the transects for a total of 100 intercept points. The methodology is according to the USDA-Natural Resources Conservation Service rangeland Natural Resources Inventory studies (USDA-NRCS 2019).

Fig. 8.2 Dry steppes on chestnut soils, #38 soil vegetation classification, Kazakh steppe, fescue-feathergrass (*Festuca valesiaca/Stipa capillata/Artemisia frigida, A. schrenkiana*; Atlas of Kazakhstan 2014). (Photo of historic reference plant community. Photo by Spaeth 2018 at Yntaly site)

Table 8.1 On-site measured field data for parameterization of the Rangeland Hydrology and Erosion Model

	S1	S1b	S2
Average annual precipitation (mm year^{-1})	359	359	359
Soil texture	Silty clay loam	Silty clay loam	Silty clay loam
Soil water saturation %	25	25	25
Slope length (meters)	50	50	50
Slope shape	Uniform	Uniform	Uniform
Slope steepness %	1 and 15	1 and 15	1 and 15
Bunch grass foliar cover %	60	45	35
Forbs and/or annual grasses foliar cover %	11	11	20
Shrubs foliar cover %	11	11	11
Sod grass foliar cover %	0	0	0
TOTAL FOLIAR COVER %	82	67	66
Basal cover %	3	2	1
Rock cover %	0	0	0
Litter cover %	31	25	10
Biological crusts cover %	0	0	0
Total GROUND cover %	34	27	11

Data represents separate model runs at 1% and 15% slopes

The Rangeland Hydrology and Erosion Model (RHEM v2.3, update 4) was used to evaluate runoff and erosion risk for different vegetation conditions representing a historic plant community reference state, a transitional state, with higher bare ground, and a degraded state with introduced annual weedy species on the site with two slope designations (1 and 15%) (Hernandez et al. 2017) (Fig. 8.3). In the U.S., government land management agencies and private land users are now using the concept of ecological sites that contain state and transition models, which are diagrammatic portrayals with narratives and identification of specific environmental drivers – states can change as a result of a natural or anthropogenic disturbance event, or lack of a natural event) (Westoby et al. 1989; Bestelmeyer et al. 2017) (Fig. 8.4). State and transition models are commonly used in conservation planning and for assessment and monitoring vegetation changes and health status of

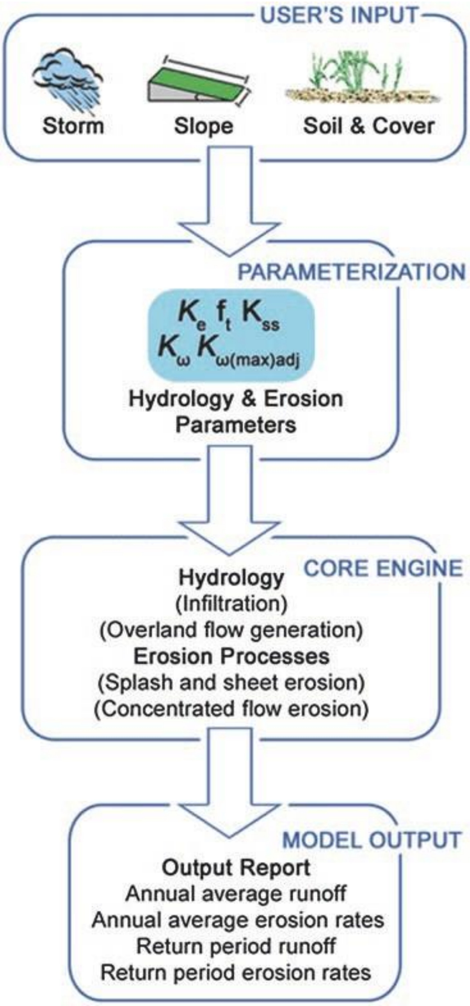

Fig. 8.3 A flowchart of Rangeland Hydrology and Erosion Model (RHEM), from https://apps.tucson.ars.ag.gov/rhem/about

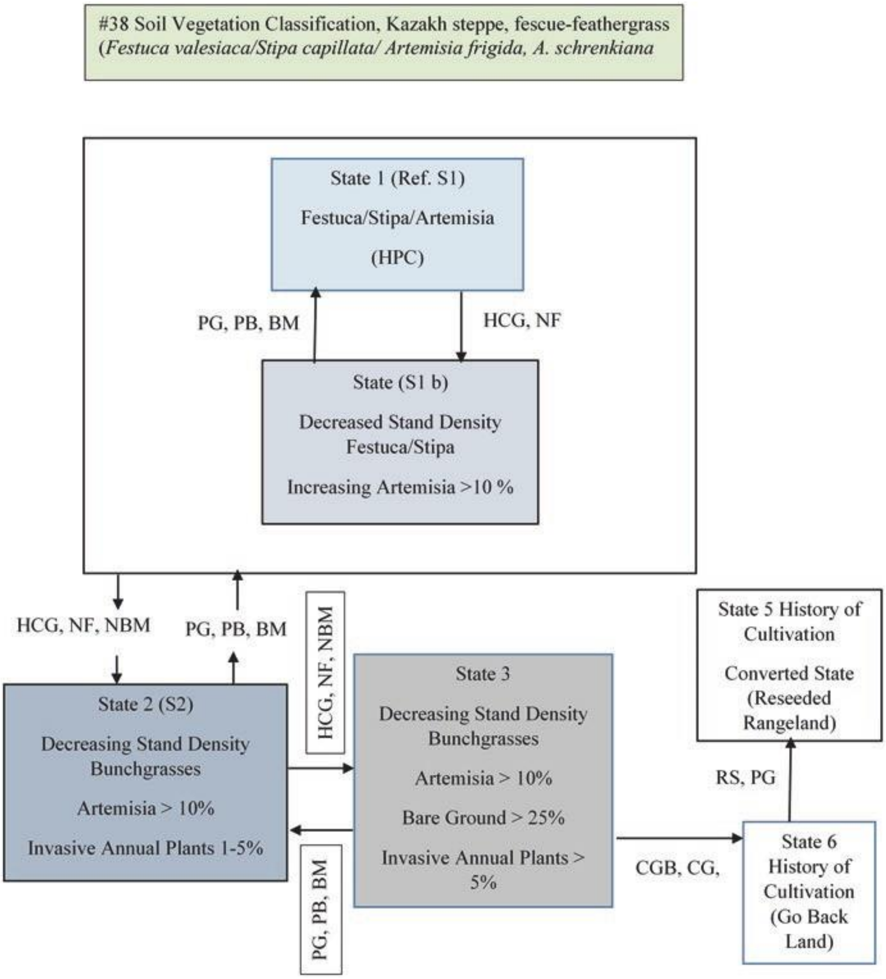

Fig. 8.4 State and transition diagram for #38 soil vegetation classification, Kazakh steppe, fescue-feathergrass (*Festuca valesiaca/Stipa capillata/Artemisia frigida, A. schrenkiana.* (*HPC* Historic Plant Community, *PG* Prescribed Grazing, *PB* Prescribed Burning, *BM* Brush Management, *HCG* Heavy Continuous Grazing, *NF* No Fire, *NBM* No Brush Management, *RS* Rangeland Seeding, *CGB* Cultivation Go-back, *CG* Continuous Grazing)

rangeland ecological sites (Carpenter and Brock 2006; Forbis et al. 2006; King and Hobbs 2006; Bestelmeyer et al. 2004, 2009).

The Rangeland Hydrology and Erosion Model was developed in a coordinated project between three USDA agencies: Agricultural Research Service (ARS), Natural Resource Conservation Service (NRCS), and the U.S. Forest Service (USFS) (Wei et al. 2009; Nearing et al. 2011). The RHEM model is designed for government agencies, land managers, and conservationists who need sound, science-based technology to model and predict runoff and erosion rates on rangelands and to assist in assessing rangeland conservation practice effects. The RHEM model is a physically based erosion prediction tool for rangeland applications. It is based on fundamentals of infiltration, hydrology, plant science, hydraulics, and erosion mechanics. The RHEM model was developed from rainfall simulation experiments conducted at more than 25 geographic sites, which represented grassland, shrubland, and woodland sites throughout the western U.S (Nearing et al. 2011). Site environmental variables are used as RHEM model inputs [soil texture, slope length, slope steepness, slope shape, dominant plant life form, percentage of canopy cover, and percentage of ground cover by component (rock, litter, basal area, and microbiotic crusts)]. Climate (precipitation intensity, duration, and frequency) is estimated with the Climate stochastic weather generator (CLIGN, Nicks et al. 1995) containing 300 years of daily precipitation data. The RHEM model provides estimates of the average annual soil loss during a 300-year time span and for 2-, 10-, 25-, 50-, and 100-year return runoff events, which provide an assessment of site vulnerability from heavier than average rainfall storm events and the consequences of accelerated soil loss from raindrop splash and sheet-flow, and rill soil-erosion processes.

8.3 Results and Discussion

Vegetative cover and biomass have a major effect on hydrology and soil loss as indicated by numerous field studies (Tromble et al. 1974; Wood and Blackburn 1981; Gifford 1985; Blackburn et al. 1986; Thurow et al. 1986; Wilcox et al. 1988; Abrahams and Parsons 1995; Spaeth et al. 1996; Weltz et al. 1998; Williams et al. 2014; Nouwakpo et al. 2018). In addition, rainfall simulation experiments have shown that plant life form and individual species (taxa) also can have a profound influence on hydrology and erosion (Dee et al. 1966, Spaeth et al. 1996; Pierson et al. 2002). Levels of foliar cover necessary for site protection against accelerated soil erosion on rangelands vary from 20% in Kenya (Moore et al. 1979) to 100% for some Australian conditions (Costin et al. 1959). Most studies indicate that cover of 50–75% is probably sufficient (Wood and Blackburn 1981; Gifford 1985; Weltz et al. 1998; Pierson et al. 2011; Pierson and Williams 2016; Williams et al. 2014, 2016; Cadaret et al. 2016a, b) to prevent degradation from accelerated soil erosion processes.

On the Yntaly site, three vegetation states were identified: a reference state (Ref S1) representing the historic plant community dominated by *Stipa capillata;* a state phase with a history of heavier grazing, and higher bare ground (S1b); and a completely transitional state where introduced weedy grasses and forbs were present (S2). According to RHEM estimates at 1% slope, for Ref S1, about 22% of the total annual precipitation (rainfall) is lost through runoff with 82% foliar cover and 34% ground cover. Average soil loss was estimated as 0.4 t ha^{-1} year^{-1} for this site (Table 1). These estimates are considered baseline and represent values expected for a *Stipa* bunchgrass plant community. Soil loss tolerance rate (T) was estimated < than 4.5 t ha^{-1} year^{-1}. The stability in hydrologic function in Ref S1 is due to dominance of bunchgrass foliar and ground cover with no connected bare interspaces.

On the transitional phase (S1b) runoff was about 24% of total annual precipitation with 67% foliar cover, 27% ground cover, and 0.6 t ha^{-1} $year^{-1}$ soil loss (Fig. 8.5). On the degraded site (S2), foliar cover was 66% and ground cover was 11%; bunchgrasses decreased from 60% to 35% and forbs increased from 11% to 20% compared to state 1 (Table 1). Annual soil loss on S2 was estimated at 1.2 t ha^{-1} $year^{-1}$ at 1% slope (Fig. 8.5). This value is still under T; however, when the storm frequencies are examined, the 25, 50, and 100 storms can produce more than 1.0 t ha^{-1} $year^{-1}$ from a single storm. As indicated by RHEM, as slope increases, so does runoff and soil loss. In comparison, on 15% slopes, runoff on Ref S1 was 24% of the total annual precipitation, with 3.1 t ha^{-1} $year^{-1}$ soil loss. For state S1b, runoff was 26% of the total precipitation with soil loss of 6.5 t ha^{-1} $year^{-1}$ (1.4 times > T). On S2, runoff was 31% of the total precipitation with 19.6 t ha^{-1} $year^{-1}$, 4.3 times greater than T (Fig. 8.5). This level of soil erosion is unsustainable and will eventually result in loss of productivity and livestock carrying capacity.

When properly managed, *Stipa* bunchgrass plant communities representative of vegetation states Ref S1 and S1b provided adequate cover at 1–6% slopes with foliar plant cover of 82 and 67% to maintain soil loss below 4.5 t ha^{-1} $year^{-1}$ (allowable T) (Fig. 8.6c). Soil loss values for vegetation state Ref S1 remained less than T at slopes up to 15%; however, S1b soil loss exceeded T at slopes 6–15%, and state S2 exceeded T at greater that 3% slopes (Fig. 8.6c).

High intensity convective thunderstorms are typically associated with accelerated runoff, as rainfall intensity is greater than infiltration capacity. These types of storms, especially intense storms with 5, 10, 25, 50, and 100 year return intervals can cause rills, gullies, and irreparable soil loss. The probability of formation of gullies is increased under conditions of low cover and net annual primary production. The reduction in production also results in reduced aggregate stability. Heavy continuous grazing can result in, soil compaction with a corresponding increase in runoff and potential for soil loss, Long-term average soil loss on rangelands is usually not a concern on sites with adequate foliar and ground cover; however, it is the rare high intensity storms where high runoff and erosion can occur, which initiates increased water flow patterns, plant pedestalling, rills, and gullies (Weltz and Spaeth 2012).

The RHEM model indicates that high intensity convective storms can have a significant impact on this site. During 10, 25, 50, and 100 year storms, there are bursts of high intensity rainfall and soil loss. On 1% slopes this can facilitate soil loss >1 t ha^{-1} $year^{-1}$ for a single storm event on the degraded site (S2) (Fig. 8.6a). As slope increases, so does the incidence of accelerated runoff and erosion. RHEM estimates on 15% slopes shows that S2 exceeds T for the 2 through 100 year storm events (Fig. 8.6b). If the site is allowed to deteriorate to a point where considerable soil loss has occurred, an ecological and hydrologic threshold will be crossed, and depending on the site, restoration may not be possible by management alone (Weltz and Spaeth 2012). On S1b, soil loss is close to T for the 25 year storm and exceeds T for the 50 and 100 year storm frequencies. For Ref S1, soil loss remained below T

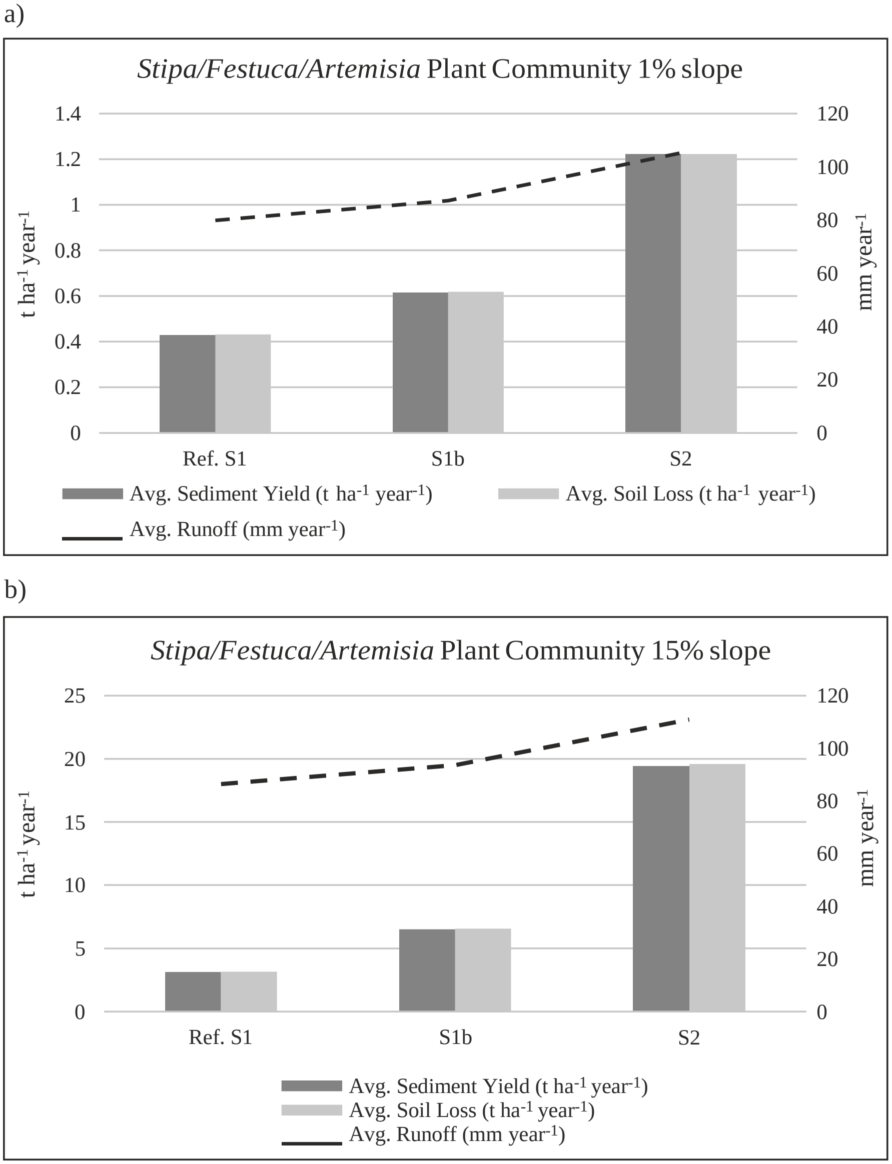

Fig. 8.5 Rangeland Hydrology and Erosion Model estimates for reference vegetation state, overgrazed state with native plants similar to reference state, and degraded state. (**a**) Average sediment yield (t ha^{-1} year^{-1}), average soil loss (t ha^{-1} year^{-1}), with average runoff (mm year^{-1}). (Ref. *S1* Reference plant community, *S1b* Native plant cover with reduced foliar and ground cover; and *S2* degraded grassland community with reduced plant cover and invasive annual species. Slope = 1%. (**b**) runoff and erosion at 15% slope)

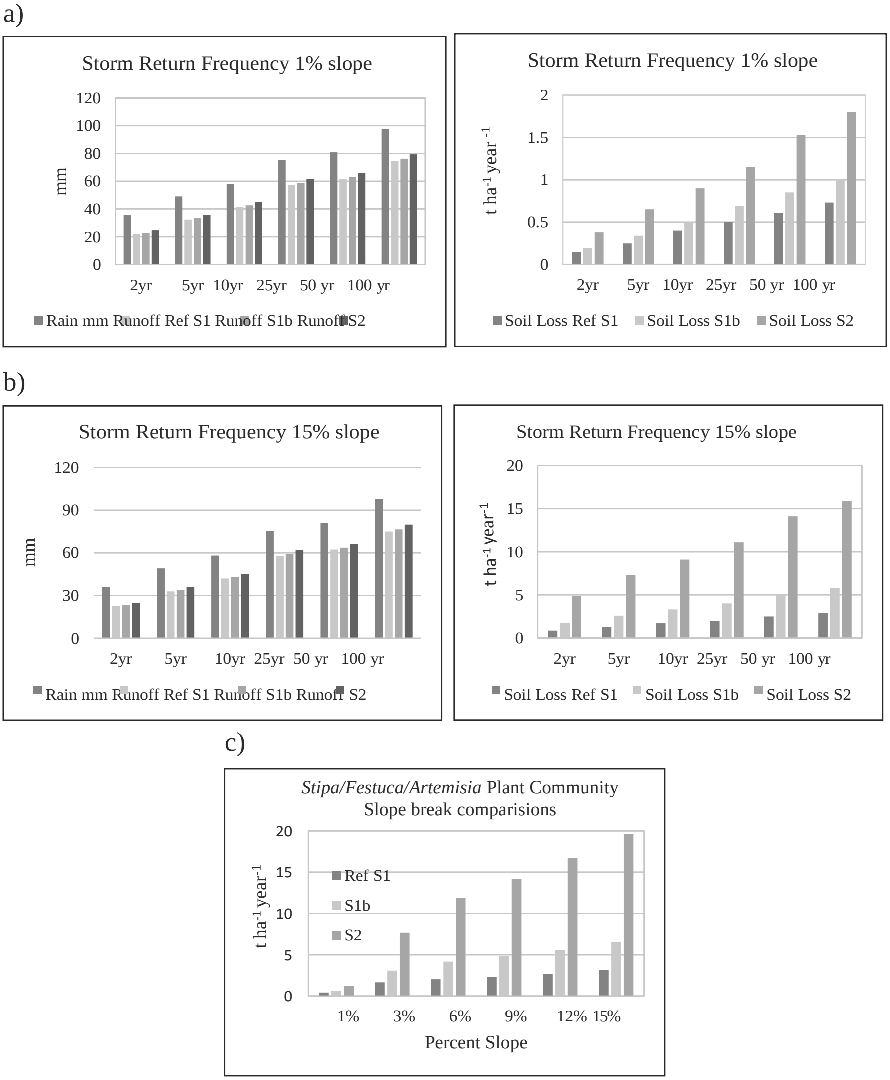

Fig. 8.6 (**a**, **b**) Rainfall, runoff, and soil loss for design storm events; and soil loss at 1% and 15% slopes. (**c**) RHEM soil loss estimates for incremental 3% slope increases

for the 2 through 100 year storms. In Fig. 8.7, probabilities of yearly soil loss potentials are given. For example, for Ref S1 (1% slope), there is a 50% chance that soil loss will be less than 0.4 t ha^{-1} year^{-1}, a 30% chance that soil loss is between 0.4 and 0.6 t ha^{-1} year^{-1}, a 15% chance that soil loss will be between 0.6 and 0.9 t ha^{-1} year^{-1}, and a 5% chance that soil loss will exceed 0.99 t ha^{-1} year^{-1}. For state S1b, there is a 55% chance that soil loss can exceed 0.99 t ha^{-1} year^{-1}. For the degraded state (S2), there is a 98% chance that soil loss will exceed 0.99 t ha^{-1} year^{-1} (Fig. 8.8).

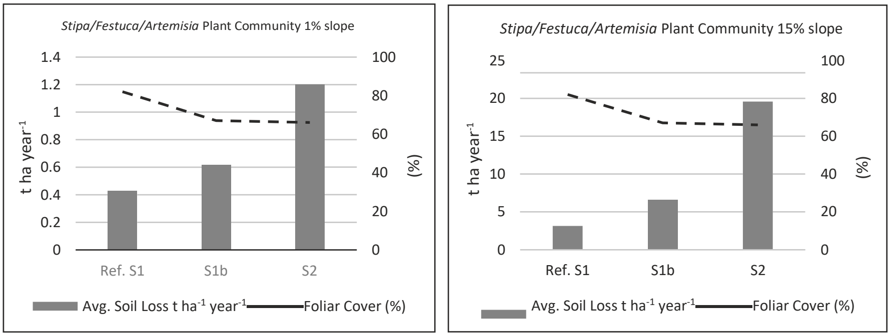

Fig. 8.7 Average RHEM estimated soil loss and foliar plant cover for reference state (Ref S1), state S1b, and state S2 at 1 and 15% slopes

In summary, foliar and ground cover are important elements in maintaining low runoff and soil loss from overland flow. In addition to foliar and ground cover, species life form and individual species can be highly correlated with infiltration, runoff, and erosion. On the Yntaly site, bunchgrasses were the dominant life form; however, on the more degraded states, foliar and ground cover was reduced with an increase in weedy forb species for states S1b and S2. This reduction was caused by heavier grazing. Over time, consistent continuous heavy grazing will cause a transition where bunchgrasses are reduced and weedy forbs increase. The shrub component can also increase; however, shrub cover was consistent at 11% cover for all three states in this study. On steeper sites, it is imperative that adequate cover of bunchgrasses be maintained to provide low potential soil loss from water erosion. On steeper slopes, the transition from a stable grassland plant community to an unstable hydrologic condition with lower plant cover and undesirable species can occur quickly. This can be documented by observing gap frequency between plants and the connectivity of flow paths as bunchgrasses are replaced with single stem forbs. The distance between plant stems increases resulting in concentrated flow and accelerated soil erosion.

Actual degradation on rangelands in Kazakhstan has been estimated at 30–60% (Kharin et al. 1986; Schillhorn-van-Veen et al. 2003). These estimates may or may not be representative of actual conditions as many of these estimates are based on coarse level remote sensing activities without any of sufficient validation of estimates via field sampling. For example, the author found many of the *Stipa* grasslands in the Kazakh steppe were undergrazed because of a lack of adequate livestock watering facilities. Rangelands in and near villages tend to be overgrazed, yet the open range at greater than 8 km from villages are not grazed at regular intervals (Fig. 8.9). Haying may occur on areas that are not directly grazed by livestock and used as supplemental winter feed.

These site-level results clearly demonstrate the usefulness of the modeling approach for holistic rangeland condition assessments; however, these site-level results may or may not the same in other geographic areas within the country, as the

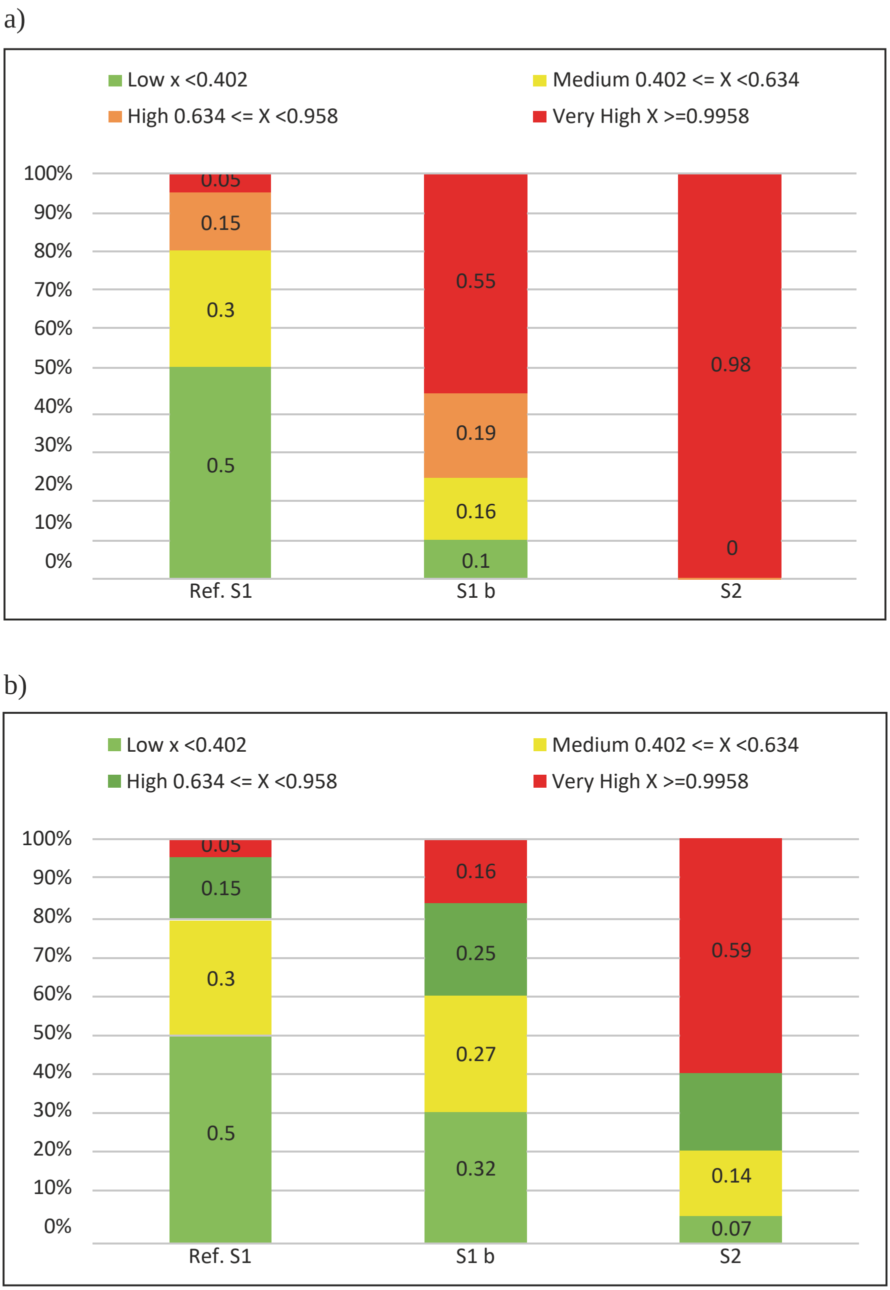

Fig. 8.8 (**a**) Probability of occurrence of yearly soil loss t ha^{-1} $year^{-1}$ for states Ref. S1, S1b, and S2, at 1% slope. (**b**) Probability of occurrence of yearly soil loss t ha^{-1} $year^{-1}$ for states Ref. S1, S1b, and S2, at 15% slope

Fig. 8.9 (**a**) *Stipa* grassland, water provided at 3 km from village, (**b**) Ungrazed *Stipa* grassland 8 km from village. (Photos by Spaeth)

soil types, climate conditions, management practices, and plant communities vary greatly across the Asian steppe. The analysis presented here is site specific to *Stipa* dominated rangeland plant communities and national policies cannot, and should not, be based on just one or even several site analyses. The generalizability of this and similar additional studies can be validated by scaling up the method from site-level to regional and national levels, using geospatial and remote sensing technologies, which remain for future projects and programs.

It would be propitious for Kazakhstan and other Eurasian countries that possess vast grassland areas, to adapt a three-tier approach to gathering critical information on status of plant diversity, protective vegetative cover, and condition of the rangeland for grazing and other uses. Remote sensing studies have been conducted in Asian countries; however, correlations between imagery with field observation has been limited. It is imperative to have reliable resource information of rangeland resources (range health and conditions) before programs are implemented to expand livestock enterprises. A robust three-tier methodology for rangeland resource assessment would include three assessment protocols that would be cross calibrated: (1) a field protocol [can be based on similar National Resource Inventory (NRI) protocols used by USDA Natural Resources Conservation Service-NRCS on rangeland] to collect vital rangeland resource data; (2) on-site drone surveillance correlated with field sample – to expand the extent of the field based sample, and (3) analyzing from remote sensing imagery with the intent to correlate all three assessment protocols. This set of three resource assessment protocols enacted regionally or throughout a country could provide vital needed resource information so that realistic and effective levels of rangeland and soil health can be determined. Accurate resource inventory information on rangeland health, vegetation composition, and use of erosion tools such as RHEM are integral to grazing management program developments to enhance the probability of achieving sustainable grazing systems that are robust and sustainable and can endure the variability in climate that is inherent on rangelands.

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