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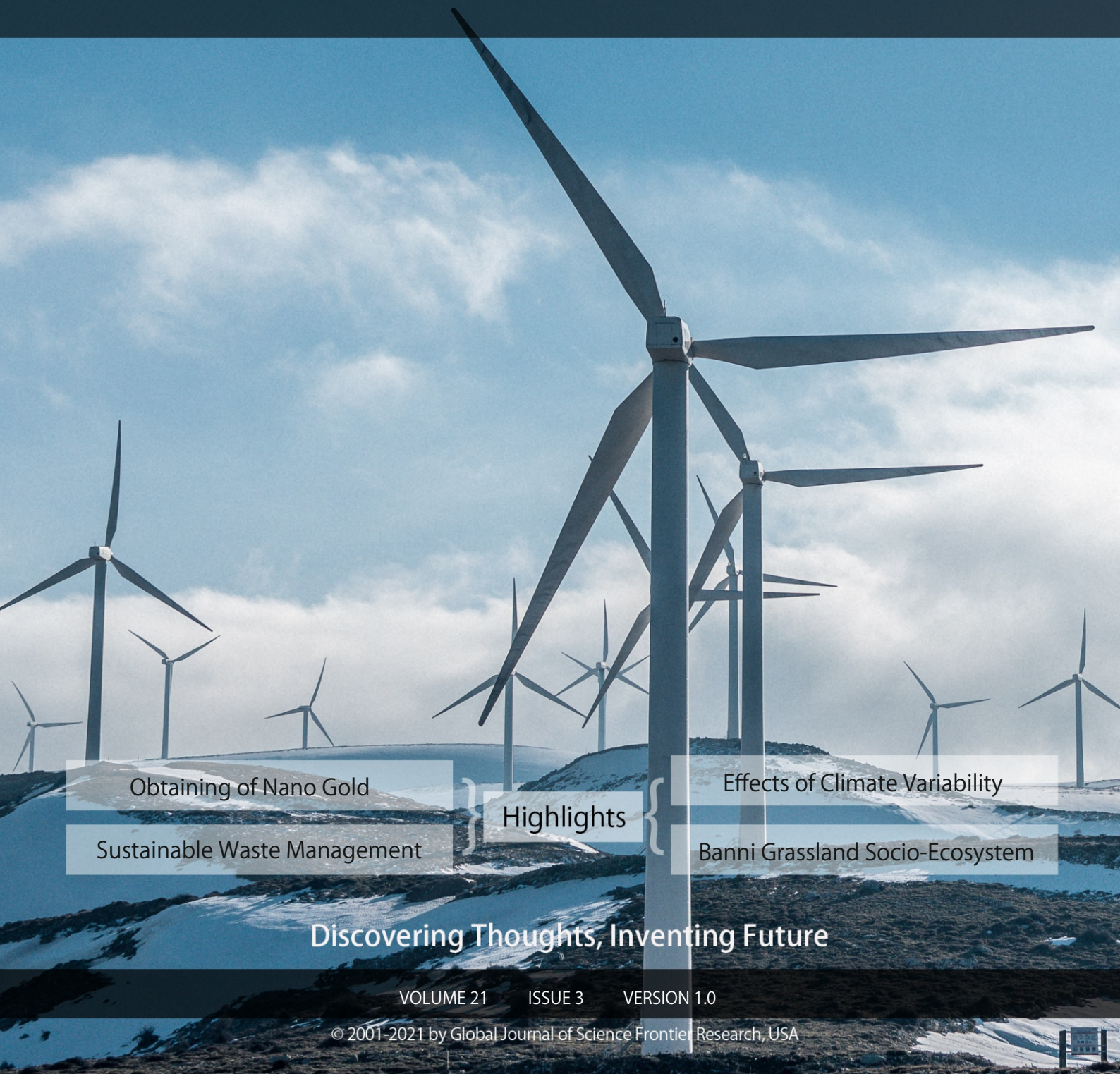

Obtaining of Nano Gold

Sustainable Waste Management

Highlights

Effects of Climate Variability

Banni Grassland Socio-Ecosystem

Discovering Thoughts, Inventing Future

VOLUME 21 ISSUE 3 VERSION 1.0

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Obtaining of Nano Gold from Concentrate (Banská Hodruša, Slovakia) using Algae with Utilization of Mechanochemical Activation

By Jana Ficeriová, Erika Dutková & Jarmila Harvanová

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Abstract- The difficult and predominantly toxic processing of sulphide concentrates with a low gold content has prompted the finding of a more efficient and environmentally friendly method of obtaining this noble metal. This work was therefore focused on the recovery of gold from the concentrate of refractory sulphide complex (Banská Hodruša, Slovakia) using a non-cyanide mechanochemico-biological process. Gold in this complex concentrate is physically located in the intercrystalline space of sulfide minerals and fills in structural defects in sulfides. The precipitation of gold from the complex mineral matrices of the concentrate can be achieved using a mechanochemico-biological process. This innovative process makes it possible to recover gold by applying a thiourea solution, which is a preferred alternative to toxic a cyanidation. The use of a biological process with the application of algae has shown that algae with siliceous structures make it possible to obtain gold from a complex concentrate (Banská Hodruša, Slovakia) with dimensions of the nano. Limnetic algae (diatoms, golden algae) are part of aquatic ecosystems and form the largest of biomass of all plants on Earth. Mechanochemicobiological process is a method that allows to obtain 100 nm gold nanoparticles from refractory sulphide concentrate (Banská Hodruša, Slovakia).

Keywords: *gold, concentrate, algae, mechanochemical activation.*

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Jana Ficeriová [α], Erika Dutková [σ] & Jarmila Harvanová [ρ]

Abstract- The difficult and predominantly toxic processing of sulphide concentrates with a low gold content has prompted the finding of a more efficient and environmentally friendly method of obtaining this noble metal. This work was therefore focused on the recovery of gold from the concentrate of refractory sulphide complex (Banská Hodruša, Slovakia) using a non-cyanide mechanochemico-biological process. Gold in this complex concentrate is physically located in the intercrystalline space of sulfide minerals and fills in structural defects in sulfides. The precipitation of gold from the complex mineral matrices of the concentrate can be achieved using a mechanochemico-biological process. This innovative process makes it possible to recover gold by applying a thiourea solution, which is a preferred alternative to toxic a cyanidation. The use of a biological process with the application of algae has shown that algae with siliceous structures make it possible to obtain gold from a complex concentrate (Banská Hodruša, Slovakia) with dimensions of the nano. Limnetic algae (diatoms, golden algae) are part of aquatic ecosystems and form the largest of biomass of all plants on Earth. Mechanochemicobiological process is a method that allows to obtain 100 nm gold nanoparticles from refractory sulphide concentrate (Banská Hodruša, Slovakia). The mechanochemical activation of this concentrate and the siliceous shells of limnetic algae strains (Dinobryon, Surirella) in thiourea solution caused changes in the physicochemical properties of gold minerals as well as in their components. These structural changes, under specific conditions, had a decisive influence on the precipitation of gold nanoparticles into the thiourea solution. The gold nanoparticles were then fixed in a cell matrix on mechanochemically activated algal shells. The reason for the fixation of the gold nanoparticles was the action of biomolecules, which secreted algal cells during activation, while again preventing the chemical effect of metal ions present in the solution. Gold nanoparticles were obtained from the concentrate after less than one hour by the described mechanochemico-biological process. In the case of mechanochemical activation of the concentrate, but without activation of defined algae, the exclusion of gold nanoparticles was not even during of six hours. That was the reason, the algae had to be activated by milling to obtain gold from this sulfide concentrate.

Keywords: gold, concentrate, algae, mechanochemical activation.

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I. Introduction

Obtaining of the gold from secondary raw materials with reducing the environmental load by recycling requires a specific strategy and the use of non cyanide methods. The cyanidation is indeed highly toxic and disadvantageous because the gold in the secondary sources is finely dispersed and cannot come into contact with the cyanide solutions. A very serious problem is also of liquidation of cyanide solutions. These justified reasons should be global avoided the use of cyanide technologies in obtaining gold.

However, the release of gold from complex mineral matrixes of sulphide concentrates is possible to achieve by the application of mechanochemicobiological processes [1,2]. The non-cyanide hydrometallurgical process of obtaining gold from concentrates by thiourea solutions is a preferred alternative to the toxic cyanidation method [3]. The thiourea compared to cyanide represents an ecologically acceptable leaching agent with exceptional kinetics and selectivity. Mechanochemical processes utilize highenergy milling and intensify processes through the formation of various surface and volume defects in solids. The main advantage of mechanochemical processes compared to traditional technologies is the smaller number of technological operations, the considerably shorter time required to obtain the desired product at favorable ambient temperatures, as well as the formation of nanostructures [4].

The biological method by using of freshwater algae with silicate shells in mechanochemical processes is considered to be a more environmentally friendly and efficient method than toxic cyanidation to recover gold from refractory sulphides of gold-bearing concentrates [5,6]. Presented innovative study is focused on the application of mechanochemico-biological process enables to obtain gold nanoparticles from the refractory sulphide concentrate (Banská Hodruša, Slovakia). Mechanochemical activation of this concentrate and silica algae shells in thiourea solution increases the number of fine particles with a large specific surface area and some degree of disruption of the mineral components.

Currently present it is a necessity to deal with non-cyanide technologies of gold extraction.

II. Experiments

a) Methodology

The chemical analysis of the samples was measured on a 240FS/240Z atomic absorption spectrometer (Varian, Australia). The specific surface area SA was determined by the low-temperature nitrogen BET adsorption method using a Gemini 2360 sorption apparatus (Micromeritics, USA). The morphology of the samples was monitored by scanning electron microscopy using EDX-FE method SEM Mira 3 (Tescan, Czech Republic). The particle size distribution was measured by photon cross-correlation spectroscopy using a Nanophox particle size analyzer (Sympatec, Germany). The amorphization of the samples was evaluated by the X-ray diffractometry method.

b) Mechanochemico-biological activation

Mechanochemico-biological activation was performed in a stirring ball mill Attritor Molinex PE 075 (Netzsch, Germany) with the volume of the milling chamber 500 ml. Sample of sulphide concentrate (Banská Hodruša, Slovakia) 50 g, thiourea as the leaching medium 2 g and siliceous shells of limnetic algae of genera Dinobryon/Surirella (Třeboň, Czech Republic) 2 g together with sulphuric acid (to maintain the pH of the solution = 1) was milled with 200 ml of destilled water and 2000 g steel balls of diameter 2 mm as the milling media. The mill was operated at revolutions of milling shaft 600 min-1 for milling time 60 min at ambient temperature.

III. Results and Discussions

Complex sulphide concentrate (Banská Hodruša, Slovakia) was selected as input material for the testing acquirement of gold with the utilization of algae in mechanochemical processes. The chemical composition of this concentrate is presented in Table 1.

Table 1: Chemical composition of the sulphide concentrate (Banská Hodruša, Slovakia)

Components [g t^{-1}]		Components [%]							
Au	Ag	Cu	Pb	Zn	Fe	Sb	As	S	SiO_2
329	183	11.5	6.2	9.4	17.9	3.1	12.6	19.8	13.2

The mechanochemical activated of the complex concentrate in the mill Attritor is characterized by an increase in specific surface area. The effect of milling on the surface area of concentrate is summarized in Table 2. The original value of the surface area (0.37 m^2g^{-1}) increased to 2.8 m^2g^{-1} without the use of algae. In the case of use algae, the Dinobryon/Surirella were measured the significantly higher values of the surface area 9.5 m^2g^{-1} and 12.6 m^2g^{-1}.

Table 2: Specific surface area, SA for samples of concentrate (Banská Hodruša, Slovakia). Non-activated, mechanochemical activated (MA) and mechanochemical activated (MA)/type of algae.

Samples	S_A [m^2 g^{-1}]
Non-activated concentrate	0.37
MA concentrate	2.8
MA concetrate/Dinobryon	9.5
MA concetrate/Surirella	12.6

The milling in stirred ball mill was led to amorphization of the gold-bearing minerals present in the concentrate, which ones decompose following of mechanochemical process with the utilization of algae to set nano gold free in the leach. The significant change after due to intensive milling was increased of the input value of the amorphization of the non-activated concentrate to 63 % without the use of algae (Table 3). In the case of use algae, Dinobryon/Surirella in the mechanochemical process were measured the considerably higher values of amorphization 86 to 91 %.

Table 3: Amorphization, A for samples of concentrate (Banská Hodruša, Slovakia). Non-activated, mechanochemical activated (MA) and mechanochemical activated (MA)/type of algae

Samples	A [%]
Non-activated concentrate	0
MA concentrate	63
MA concetrate/Dinobryon	86
MA concetrate/Surirella	91

Mechanochemical activation of sulphide concentrate (Banská Hodruša, Slovakia) and siliceous shells of specified limnetic algae of genera (Dinobryon, Surirella) in the thiourea solution caused changes in the physico-chemical properties of gold minerals as well as algae mineral constituents. These structural changes had a decisive influence on the formation of gold nanoparticles (100 nm) into thiourea solution under the specific reaction conditions mentioned above, from which they were subsequently fixed in the cellular matrix of mechanochemically activated algal shells. The cause of the formation of gold nanoparticles was the action of biomolecules that algal cells secrete while they defend against the chemical effect of metal ions present in the solution. In the case of thiourea leaching of activated sulphide concentrate in the presence of non-activated algae, no nanoparticles of gold were obtained even after one day (Figures 1A, 2C). Nanoparticles of gold were obtained after fifty minutes by described the mechanochemico-biological process after activating the concentrate and algae at the same time (Figures 1B, 2D).

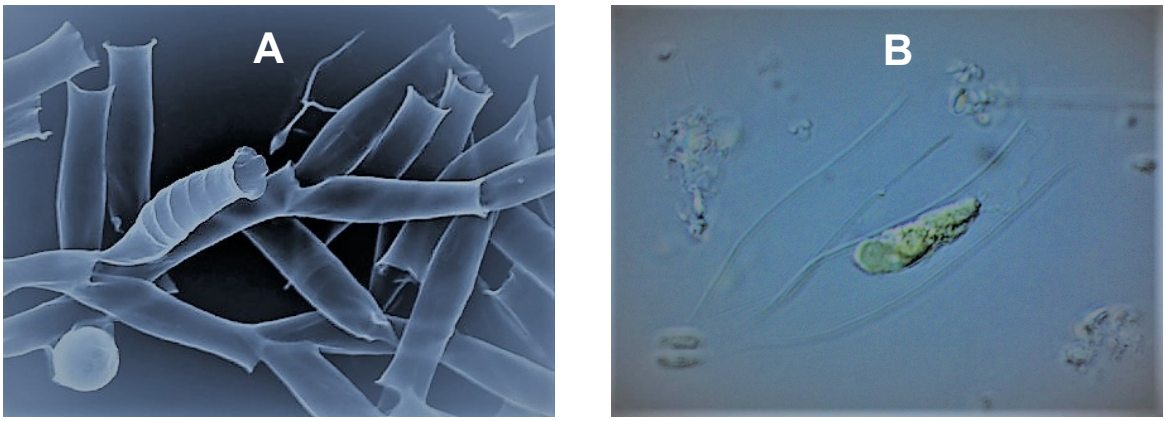

Figure 1: SEM micrograph of the: A - Non-activated sample algae Dinobryon and activated sample sulphide concentrate, B - Mechanochemical activated sample (sulphide concentrate and algae Dinobryon), gold nanoparticles attached in algal cells

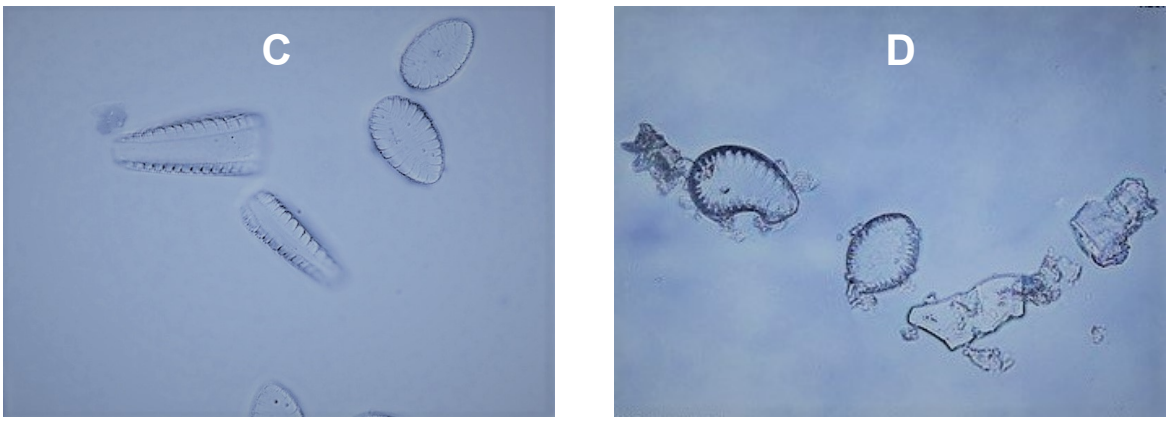

Figure 2: SEM micrograph of the: C - Non-activated sample algae Surirella and activated sample sulphide concentrate, D - Mechanochemical activated sample (sulphide concentrate and algae Surirella), gold nanoparticles attached in algal cells

IV. Conclusion

The nanoparticles of gold obtained by the described way may have different uses in practice, such as accelerating the decomposition of hazardous substances or eliminating pollutants in contaminated water, soil, and air. Acquirement nanoparticles of gold through this process would also lead to the elimination of algae from the aquatic environment where they are dangerous not only for aquatic plants and animals but also for humans. For example, such an aqueous environment with algae Dinobryon and Surirella from the site (Třeboň, Czech Republic) are shown in Figures 3 and 4. It is generally known that defined algae absorb carbon dioxide and emit oxygen, thus playing an important role in preserving life on Earth.

Figure 3: The aquatic environment with algae Dinobryon (Třeboň, Czech Republic).

Figure 4: The aquatic environment with algae Surirella (Třeboň, Czech Republic).

Acknowledgement

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Land Degradation and Restoration Driven by Invasive Alien - *Prosopis Juliflora* and the Banni Grassland Socio-Ecosystem (Gujarat, India)

By Uriel N. Safriel & V. Vijay Kumar

The Hebrew University of Jerusalem

Abstract- Land Degradation and alien species invasions gained significant attention of the scientific community and the intergovernmental establishment. This review presents a case in which these two processes jointly interact with an ecosystem – the Banni grassland – and its users over six decades. Banni is an arid, yet productive rangeland that supports a pastoral community raising grass-cover-dependent livestock. A bush/tree alien species, *Prosopis juliflora*, initiated a land degradation process by outcompeting the grass-cover species, thus undermining the pastoral livelihood. Rather than yield to the prevailing approach of eradicating an invasive species, the community and authorities considered cultural, scientific, and policy issues, and worked together to initiate linked processes of the invasive species naturalization and the grassland ecosystem transformation, to a mosaic of grassland and bush/tree woodland patches ecosystem.

Keywords: banni, kachchh, charcoal, prosopis juliflora, land degradation, ecosystem services, alien invasive species.

GJSFR-H Classification: FOR Code: 960599

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Keywords: banni, kachchh, charcoal, prosopis juliflora, land degradation, ecosystem services, alien invasive species.

I. Introduction

Land degradation (also labelled 'desertification' when in drylands), restoration of degraded lands, and invasive alien species, have each been spotlighted in thematic assessments of the IPBES: the 2018 "Land Degradation and Restoration" and the 2021"Invasive Alien Species"). Land degradation is often expressed as long-term reduction or loss of biological productivity which is of value to humans; invasive alien species are species introduced into locations off their natural distribution range, where they then impact the new area's biodiversity and ecosystem services. The terms "land degradation" and "invasive alien species" both are colored by negative overtones ('degradation', 'invasion'), and they are habitually presented as "serious and rapidly growing threats" to livelihood security (IPBES 2018). Although assessed and often attended separately, these two entities often interact, such that the above threat is often exacerbated. This interaction, however, is not sufficiently understood and deserves further research (*e.g.,* Richardson and Van Wilgen, 2004); Shackleton *et al.,* 2014).

This review paper presents a case study largely based on secondary data analysis of this land degradation-invasive alien interaction, in an Indian arid grassland ecosystem invaded by an alien plant, and highlights its half-century vicissitudes in a social-ecological system, *i.e.*, the Banni Grassland degradation and its restoration, both driven by the same invasive alien *Prosopis juliflora* (*Pj* in this study).

II. Banni Grassland Socio-Ecosystem

a) The Banni grassland

The Banni (meaning 'newly created') grassland is a cloud-shaped area extending 2,618 km^2(GUIDE, 2007) in the north-western area of India's state of Gujarat (230 19' - 230 52' N). It is bounded by a huge marshy salt desert (Great Rann of Kachchh) at its northern border and a smaller one to its south (Fig. 1). It is regarded as the only remaining single natural vast stretch of grassland in the Indian sub-continent, and, despite the inherent salinity of its alluvial sandy lands, it is seen as Asia's finest Grassland (GUIDE, 1998).

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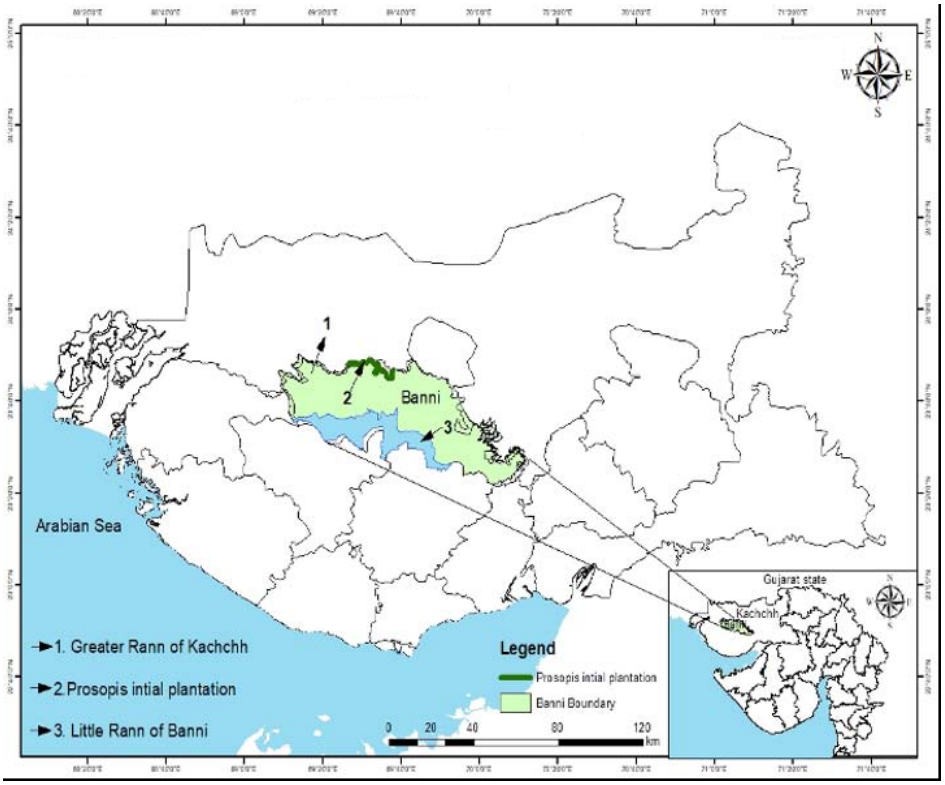


Figure 1: Banni grassland in Kachchh district of Gujrat State with site of Pj Introduction (arrow 2)

Banni soil is saline due to saline groundwater surfacing through capillary movement, and then evaporating under the arid dryland climate (335 mm average annual rainfall, and frequent droughts (26 from 1932-2008), thus leaving salt deposits on the topsoil (Kumar *et al*, 2011). The topsoil also has low water permeability (0 to 0.13 cm/hr.) due to its high proportion of silt and clay, causing flooding and water logging (Singh and Kar, 2001). The level of soil salinity varies spatio-temporally, depending on the specific site's distance from the bordering marshy saline desert areas, and on the frequency and intensity of the seasonal leaching effect of freshwater flow from seven rivers that include Banni in their catchment areas. Together, the areas of highly saline (over 15.0 M mhos/cm) topsoil are spread over 51% of Banni (Soil Survey Division 1986; GUIDE, 1998). In spite of these harsh abiotic environmental features, Banni is endowed with relatively rich biodiversity (91 plant species, 81% of them common, GUIDE, 2011) typical to productive grassland ecosystems, and since 1955 it has been credited with the legal status of an Indian "protected forest".

b) The Banni people and livelihoods

Given records as of the 18th century Banni people's roots are in Banni's adjacent Sindh desert, where they practiced a pastoral lifestyle based on livestock grazing, and temporarily settle in Banni. In the early 19th century, these family/clan settlements gradually increased in permanency until they qualified as "villages", even though they maintained the traditional Banni–Sindh nomadism. However, in the late 19th and early 20th century, the ruler of the principality in which Banni is embedded (currently Kachchh district, see Fig. 1) declared the area a "Reserved Grassland", in which settlement is forbidden, thereby reinforcing the Banni–Sindh desert nomadism.

Following India's independence in 1947, the Indian state of Gujarat allowed grazing in Banni, but imposed livestock-head taxing, abolished in the mid-1960s. This, together with the India-Pakistan partition, deterred the Banni–Sindh nomadism. These policy-social-cultural processes increased livestock and human populations and encouraged permanence in an increasing number of small residential settlements (48 "villages" by 2015). Each village comprised a cluster of small family/clan houses positioned next to a local water source (Trivedi, 1965) and surrounded by grassland areas where free-ranging livestock forage, such that the entire Banni grassland became available for grazing.

The India-Pakistan partition of 1947 and the abolishment of the livestock tax in the mid-1960s led to further reduction of the Banni–Sindh nomadism. Gradually the pastoral livestock owners settled in the permanent residential settlements, with livestock (primarily cattle and seconded by buffalo) the mainstay of their livelihood, while sheep and goats were common in number but not that economically significant (for this paper 'livestock' is used for cattle and buffalo only).The overall grazing condition of the Banni was fair; the livestock depended solely on the forage provisioning service of the Banni grassland ecosystem (green forage

production of 465 tons/grassland ha), with no overgrazing and no added or stored fodder, except in drought years, when the herds migrated to less arid areas in southern Gujarat and its southern border state of Saurashtra.

Figure 2: The Banni Kankerj breed bull

The Banni grassland herders were unique in that their grass-depended livestock products were used not only for their own consumption and subsistence, but also engaged in income generation, primarily by sale of bullocks for traction, land ploughing and levelling. Thus, the Banni people, locally called Maldharis (cattle breeders), are known not only as livestock herders, but also for their skills in breeding superior cattle and buffalo breeds, including the Kankrej breed (Fig. 2) – the heaviest cattle breed of India, highly adapted to extreme and prolonged drought conditions. Unlike a livelihood based on livestock products, whose success is subject to Banni's climate variability, bull breeding is a drought-proof adaptation; in rainy years the bulls are reared, and in drought years they are sold. The Maldharis's traction bulls are regarded as one of the best breeds in India and were sold in most parts of Gujarat, as well as in neighbouring states. In 2011 for example, a price of a Banni bull was about five times higher than that of a Kankrej cow, and its yearly average sale of ca 15,000 bulls jointly fetched $15,385 to $18,462, what supported 6,000-10,000 villagers (Mahajan&Bharwada, 2011).

Furthermore, the Kankrej breed has a high milk yield. Traditionally, the milk's significance is not in its market value (and hence should not be sold), but rather for its importance in nourishing the calves, thereby maintaining the quality of the breed (Trivedi, 1965). On the other hand, milk production of the Khunni buffalo – a local indigenous breed (Fig. 3) that is also highly adapted to the Banni environment – is among the heaviest and highest milk productive breed in India.

Thus, although the buffalo is used mostly for the herders' subsistence, it also generates income through the production of ghee, a buffalo milk product of high fat concentration, used not only by the herders, but also sold locally.

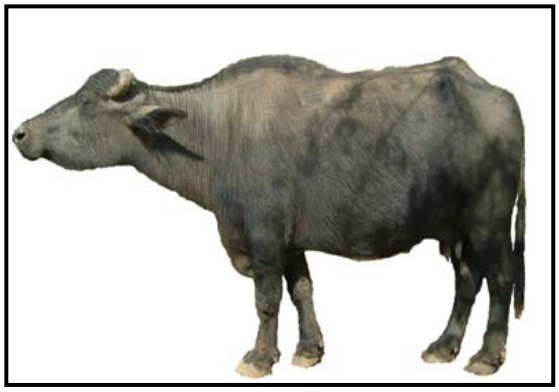


Figure 3: Khunni Breed buffalo

III. The Alien Invasive *Prosopis Juliflora*

a) The plant and its native range

Prosopis juliflora is an evergreen thorny leguminous shrub/small tree of 3-15 m tall but usually up to about 5 m tall, and the 20 to 30 cm long pods are in clusters of 2 to 5 at the ends of the spreading branches. It is native to the arid and semi-arid zones of the subtropical and tropical regions of northern South America, southern Central America and the Caribbean (Fig. 4).

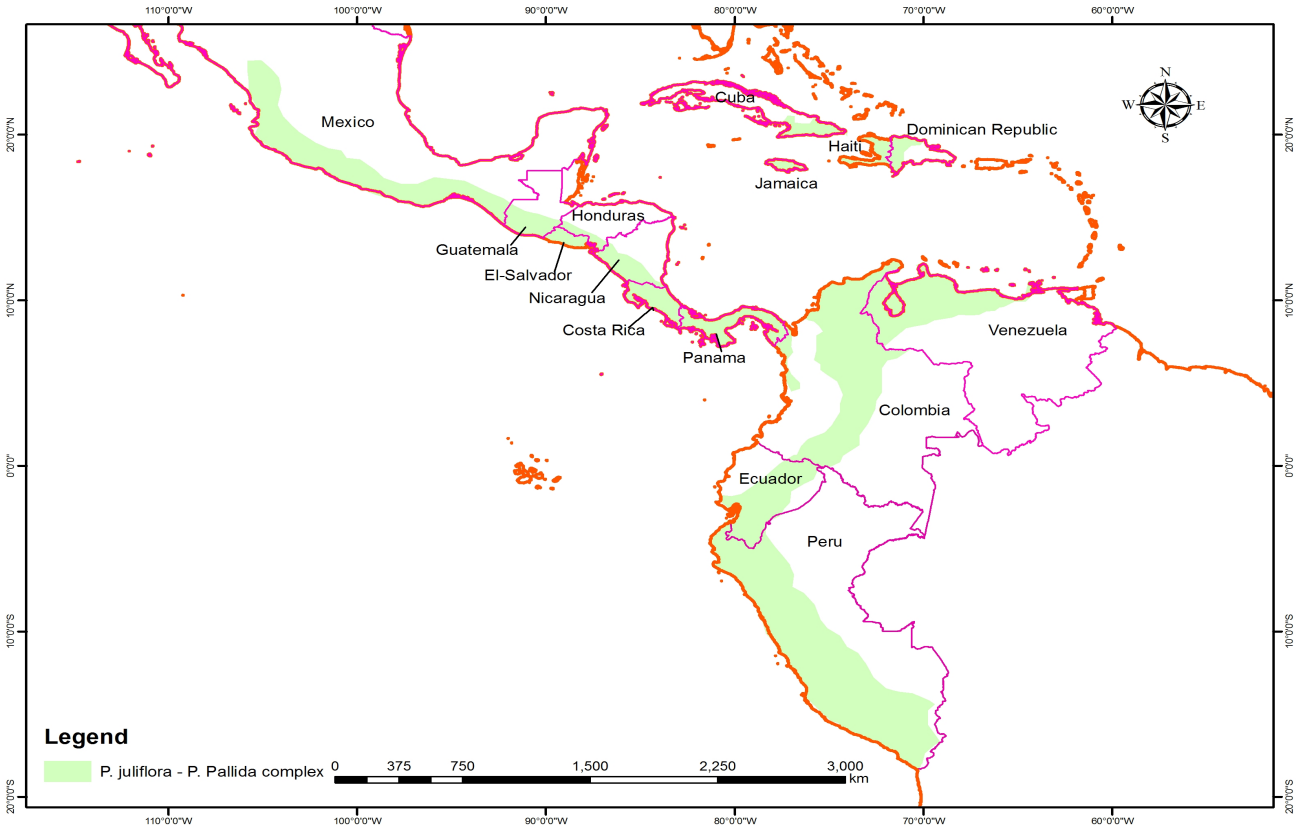


Figure 4: *Pj* native distribution (in green) Adapted from Pasiecznik *et al.* (2001).

Related species, *Prosopis pallida* is also native to these regions, whose center of distribution is in Peru, whereas that of *P. Juliflora* is in Ecuador and Columbia, and a hybrid zone of the two occurs in northern Peru, Ecuador and southern Colombia. Due to their similarity and hybridization, they have often been misidentified to the extent that an in-depth review (Pasiecznik *et al.,* 2001) recommends attending a "*P. juliflora - P. pallida* complex" rather than each separately. Given the specific source of the plants introduced to Banni grassland, some characteristic of the invading plants, and the prevailing naming by stakeholders, for the purpose of this paper the Banni grassland invader alien is labelled as *Prosopis juliflora* (hereafter cited as *Pj*).

In its native range *Pj* occurs in thickets (Central America and the Caribbean, Pasiecznik *et al*., 2001) or mixed with other species in scrub vegetation (southernmost Ecuador [Neill, 2015]) and Galapagos (Wiggins and Porter, 1971). As of the 1800s *Pj* populations in their native ranges have been often the source of *Pj* "weedy invasions" of neighbouring areas. These population spreads were triggered by deforestation of invaded areas converted to rangelands and cultivated lands (Pasiecznik *et al.*, 2001). It is likely that these rather local weedy invasions triggered by land use changes demonstrate the qualities of *Pj* in withstanding a wide range of environmental conditions and in rapid production of fuel wood and timber, attributes that encouraged the intentional introductions of *Pj* to many countries as of the late19th Century (Senegal, year 1822), and further introductions to the Americas (2 countries), Oceania (3 countries), Africa (25 countries) and Asia (18 countries), mostly motivated by fuel wood shortage (Mwangi and Swallow, 2005). In most countries to which *Pj* had been introduced, thus millions of hectares, mainly of rangeland have already been, and are still being invaded (Pasiecznik, 1999) such that in 2004 *Pj* ranked as "one of the world's top100 worse invasive species", by the Invasive Species Specialist Group of the IUCN. Major areas already invaded are in Argentina, the Sahel countries, Kenya, Australia and in most of the arid and semiarid regions of India.

b) Pj introduction to Banni – sources, periods and motivation

Pj first arrived to India from Mexico to Sindh, an arid region north of Banni (currently in south Pakistan) in 1857 (Reddy, 1978; Muthana and Arora, 1983). Later introductions to India have been: from Jamaica to the State of Andhra Pradesh (far south of Banni) in 1877 (Raizda and Chatterji, 1954; Reddy, 1978); from Peru, Mexico, Argentina and Uruguay to many parts of India in 1915-1916 (Burkart, 1976); from Mexico, introduced for

stabilizing sand dunes in Rajasthan's Thar Desert during the 1930s, where it was officially declared a "royal plant" to be protected (Muthana and Arora, 1983); and from Mexico and Africa, for planting close to the city of Morbi in the Gujarat region of Kachchh, ~100 km from Banni in the 1930s, for "fighting desertification" (TNN, 2004). Thus, by 2000, *Pj* covered nearly 40% of India (Tewari *et al*., 2000) and, with 43 million trees, became the dominant tree of Gujarat (TNN, 2004).

But not until 1960s was *Pj* introduced to Banni by the Gujarat State Forest Department, an introduction driven by a trend of intensifying soil salinization beyond the values inherent to the Banni area. The increased salinity was triggered by two policy interventions: 1) check-damming of rivers (see 2.1.), which reduced the amount of salt leached from the soil (and also reduced the river-deposited supply of nutrients); and 2) new road construction for national security purposes causing diversion of seawater flow producing seawater-tidal inundation of the "Greater Rann of Kachchh," which increased the windborne salt from the Rann, thus affecting 12 villages in Banni along its northern border with the Rann (GUIDE, 1998). The increased soil salinity resulting from these two policy-driven externalities led to lowered productivity of the grassland, both quantitatively and qualitatively - an example of land degradation, i.e., "an anthropogenically driven reduction of biological productivity" (IPBES, 2018) on which most services of the Banni ecosystem and their benefits to Banni people, fully depend.

This trend of reduced productivity driven by increasing soil salinity has been visibly severe since the early 1960s, as noted in the third Five Year (1960-1965) Plan of the Gujarat State Forest Department, which described *"disappearing vegetation"* and *"conditions conducive to further desert formation"* (Government of India, 1960). The Department, impressed by *Pj*'s higher salinity and drought tolerance (relative to that of several other species it had tested), set out to plant from 1960/1961-1965, a *Pj* shelter belt in a 315 km^2 area on the northern edges of Banni (Fig. 1). The area, comprising 12% of the Banni, was intended to function as a wind breaker that would reduce the salt particles blowing in from the Greater Rann of Kachchh into Banni (GUIDE, 1998; Tewari *et al.,* 2000; Bharwada and Mahajan, 2006; GUIDE, 2011), thus protecting Banni's forage provision and supporting the herders' livelihood.

c) Pj invasion adaptations

Since its arrival in Banni in the 1960s, *Pj* has swiftly breached all post-introduction invasion barriers (survival, reproduction and spread), to become a *"self-sustaining population with individuals surviving and reproducing also at significant distance from the original point of introduction"*, thus earning the designation "invasive alien" (Blackburn *et al.,* 2011). This can be attributed in part to the plant's dryland-specific invasiveness traits. Itself a native of drylands, *Pj* is adapted to live with relatively limited resources of soil moisture and nutrients and with the constraints of high soil salinity and alkalinity. Other major invasion adaptation traits are *Pj*'s life-history variables of reproduction and survival. Flowering twice a year (starting from the first year of life, Pasiecznik *et al*., 2001) and producing 31,700 relatively large (13x0.75x0.54 cm) pods/tree/year at maturity (Felker, 1979)that cumulatively contain 805,000 relatively light-weight (0.03 gr) seeds/tree/year (Fenner, 1985; Shukla *et al.* 1984; Silva, 1986)[1], account for *Pj*'s high reproductive rate. This, combined with the plant's high survival rate at all stages -- seedling, sapling and adult tree (all of which are inedible to wild and domestic herbivores), contribute to its high population growth rate in Banni.

Moreover, another important trait, which accounts for the plant's extensive spatial spread, is its high germination rate (much higher than of Banni indigenous *Prosopis cineraria,* El-Keblawy and Al-Rawai 2006) and those in deeper soil layers remain dormant, acting as a reserve during times of scarce rainfall. In addition, high rate of *Pj* seeds become seedlings and survive to adulthood with a lengthy survival probability. These survival successes can largely be attributed to a favourable set of circumstances: To begin, unlike its inedible foliage, *Pj* pods' pulp is highly nutritional in carbohydrates, proteins, fats and minerals, and is thus palatable to and edible by livestock. Second, the season of *Pj* pods' maturation, shedding and abundance (41 tons of pods/ha of 2,053 trees/year, Gavali & Lakhmapurkar, 2009) occurs when most grass and herb species of the grassland have already been grazed by Banni livestock or are too dry for consumption, and so the livestock (mostly buffalo, which are more numerous and better adapted to pod consumption than cattle) consume these seasonally shed pods, along with their packed seeds. Finally, the thick seed coats are disintegrated by the animals' digestive tract acids – an essential pre-treatment for germination – and are excreted after having been well fertilized with adequate moisture from the animals' dung. Since Banni's livestock are free-ranging, and since a livestock animal defecate about 14 times/day (Weeda, 1967; GUIDE and GSFD, 2010[2]), most *Pj* seeds are randomly dispersed in a high diversity of germination sites at considerable distances from the parent plant. This accounts for the plant's high seedling survival rate and consequent extensive spread in Banni.

[1] Values based on averages calculated within and between sources.

[2] Weeda, 1967 address cattle only, and GUIDE and GSFD, 2010 address another observation of both cattle and Buffalo combined, when buffalo more common, but the final result is identical to that of Weeda, 1967, apparently suggest that the two do not differ much in this variable.

Pj's invasion adaptations traits for population growth and spread alone, however, are not sufficient for the plant to compete successfully with the diverse indigenous plants of Banni's thriving ecosystem. *Pj*'snative lands (see III a) are shrubland/woodland ecosystems in which *Pj* rarely dominates and is sometimes totally outcompeted, unless other tree species in the area are removed by man. But Banni is a grassland ecosystem whose salinity excludes potential tree competitors. Thus, introduced into Banni, *Pj* did not encounter dominant native tree species, but rather the grassland's 30 common native grass and 4 common native sedge species (GUIDE, 2011) with which it would compete for the scarce Banni resources with two competitive advantage traits: 1) addressing water scarcity, the plant's foliage absorbs moisture from dew and from light rains, but more important is its dual root system, with both surface lateral roots and depth vertical roots, a root system instrumental in outcompeting both topsoil-rooted annual plants and deep-rooted perennial grass species (Mooney *et al*., 1977; Pasiecznik *et al*., 2001); and 2) addressing soil nutrient deficiency, *Pj* interacts with several strains of salinity- and drought-tolerant *Rhizobium* bacteria and several mycorrhizal fungi in atmospheric nitrogen fixation (Pasiecznik *et al.,* 2001).

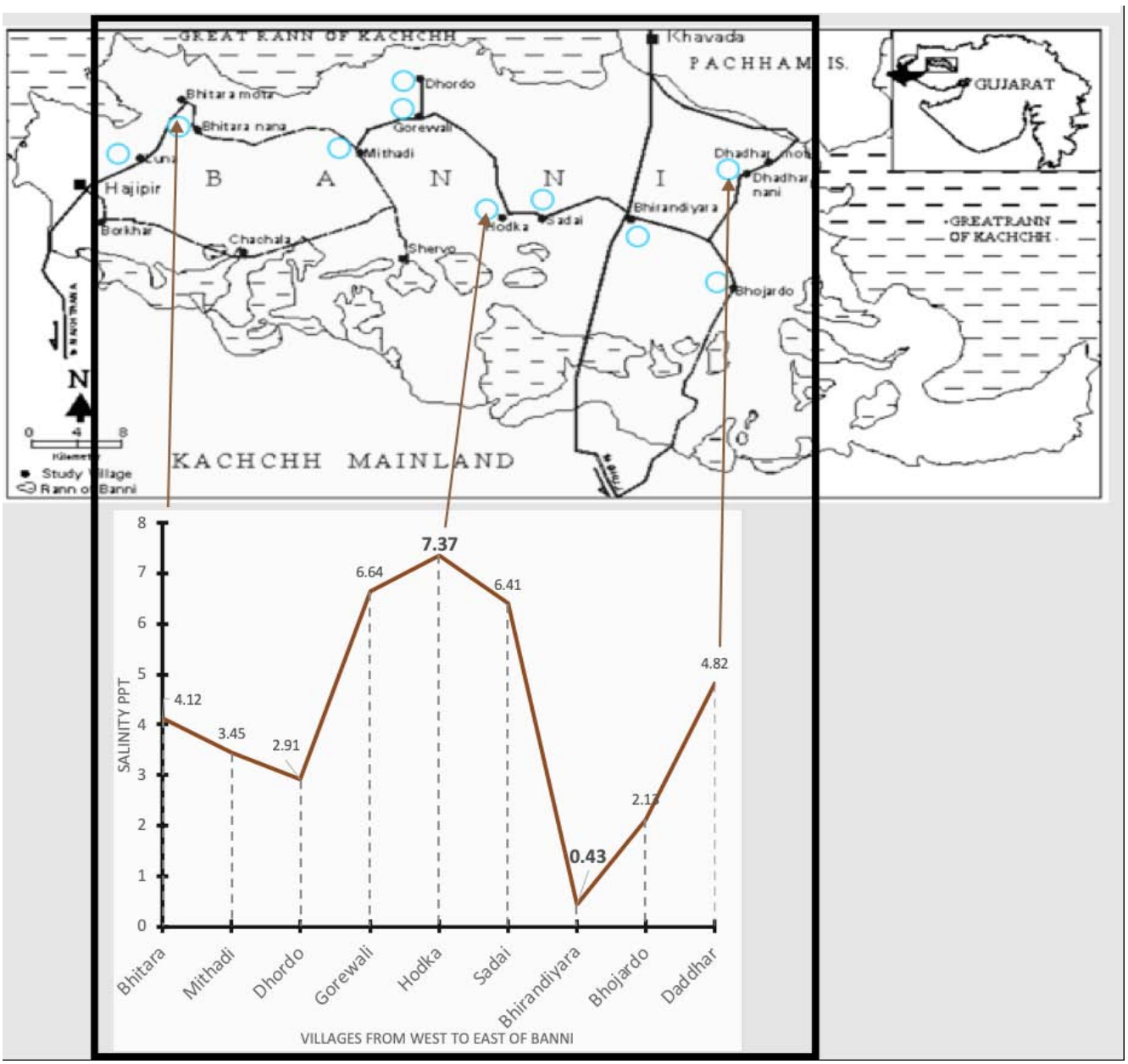


Figure 5: Banni spatial Salinity variation (year 2003) 0.43-7.37ppt.

These resource competition advantages alone may not have enabled *Pj*'s high population growth and spread in the saline Banni grasslands. *Pj* was introduced to Banni with the goal of slowing the grassland's increasing salinisation process (see 3.2) by curtailing the airborne salt input with a wind breaker tree, which itself has a high salinity tolerance (up to 36,000 mg/l NaCl, [Felker *et al.,* 1981] and 6,000 mg/l salinity with no reduction in growth [Harsh and Tewari, 2009)]).Paradoxically, this trait gave *Pj* an unexpected competitive edge over the indigenous plant species inhabiting the grassland's spatially diverse salinity levels, most of which have a lower salinity tolerance than *Pj*.

An example of the spatial variability of salinity levels of Banni lands is illustrated by a survey of nine sites covering an east-west transect of Banni, yielding a salinity range of 0.43-7.37 ppt, with a mean of 4.25±2.29 ppt, thus having a coefficient of variation of 0.5 (Fig. 5, salinity range, Gavali & Lakhmapurkar 2009). Consequently, the indigenous plant communities that inhabit Banni lands of diverse salinity levels also differ in their salinity tolerance levels. When introduced to Banni, *Pj*'s density (trees/ha) was negatively linked to the salinity level of the area it invaded (Gavali & Lakhmapurkar 2009), as well as to the number of its potential indigenous competitors: high quality palatable grass species and indigenous tree cover tolerable to "very low and "low" salinity categories; salinity sensitive nutritious grass species give way to more resilient but less nutritious species tolerate soils of "high" and "moderate" categories, and the "extreme" salinity excludes all palatable grass species (GUIDE, 1998). Thus, the higher the salinity of the invaded land, the smaller the number of species with which *Pj* invaders would need to engage and outcompete (Table 1). Thus, under Banni's environmental conditions, high salinity tolerance qualifies as *Pj*'s critical invasion adaptation trait.

Table 1: Salinity tolerance - Pj vs. Banni indigenous plants*

Salinity dS/m & Mmhos/cm	Category	#*Pj*/ha	Trees - *Acacia nitotica , Prosopis cineraria* Shrubs - *Capparis, Salvadora*	Dense, high quality palatable grass *Sporobolus, Dichnthium, Cenchrus, Sesmostachya*	Low quality palatable, Nutritious grass/salt grass, *Aeluropus logopoides*	Sparse, mostly non palatable, Low nutritious grass *Eurochondra setulosus*
<1	Very low	2580				
<3	Low	2440				
<8	Moderate	2220				
<15	High	970				
>15	Extreme/Very high	Sparse				

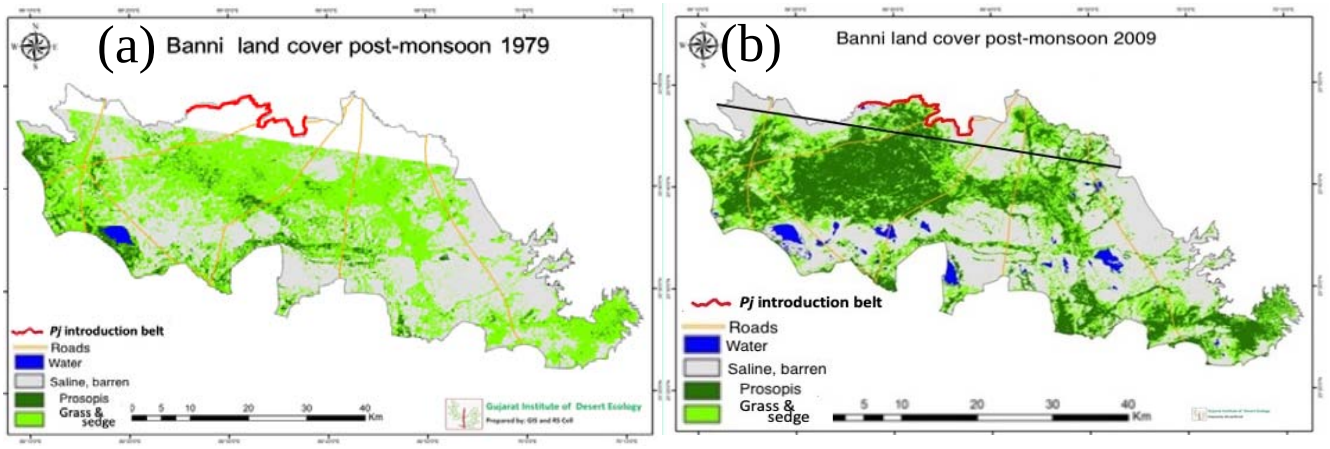
* indigenous are tolerant to the salinity category;
Indigenous are intolerant, and can be replaced by *Pj.*

Added to its advantage in resource competition, apparently intensified by its high salinity tolerance, *Pj* also employs interference competition, as some of its leaf, fruit and seed chemicals function as allelochemicals that negatively impact the growth and seedling germination of neighbouring plants (Noor *et al*. 1995). Furthermore, *Pj* reduces its vulnerability to insect herbivory and to large herbivores' browsing by investing in yet other leaf chemicals, mainly alkaloids and tannins that deter insects and make leaves non-palatable to mammal herbivores, whose browsing is also impaired by *Pj*'s 0.5-4 cm long thorns (Pasiecznik *et al.*, 2001). Jointly, these attributes endow *Pj* with a high potential for competitively monopolizing land resources, leading to rapid attainment of stable population size at the carrying capacity of the invaded Banni grassland ecosystem. With this, *Pj*'s introduction to Banni grassland's northern border (Fig. 1) in the early 1960s triggered a sequence of ecological, social, economic, and policy changes in Banni and beyond.

IV. The Invasion And Its Impact

a) *Pj invasion following introduction*

Upon its introduction into Banni, *Pj* encountered two land-cover challenges – competing with the dense grass species communities and coping with the vegetation-barren, high salinity areas. Throughout the first post-introduction decade, *Pj* sparsely invaded the former and largely avoided the latter (Fig 6a).



* (a) Image of 1979, with northern section masked;

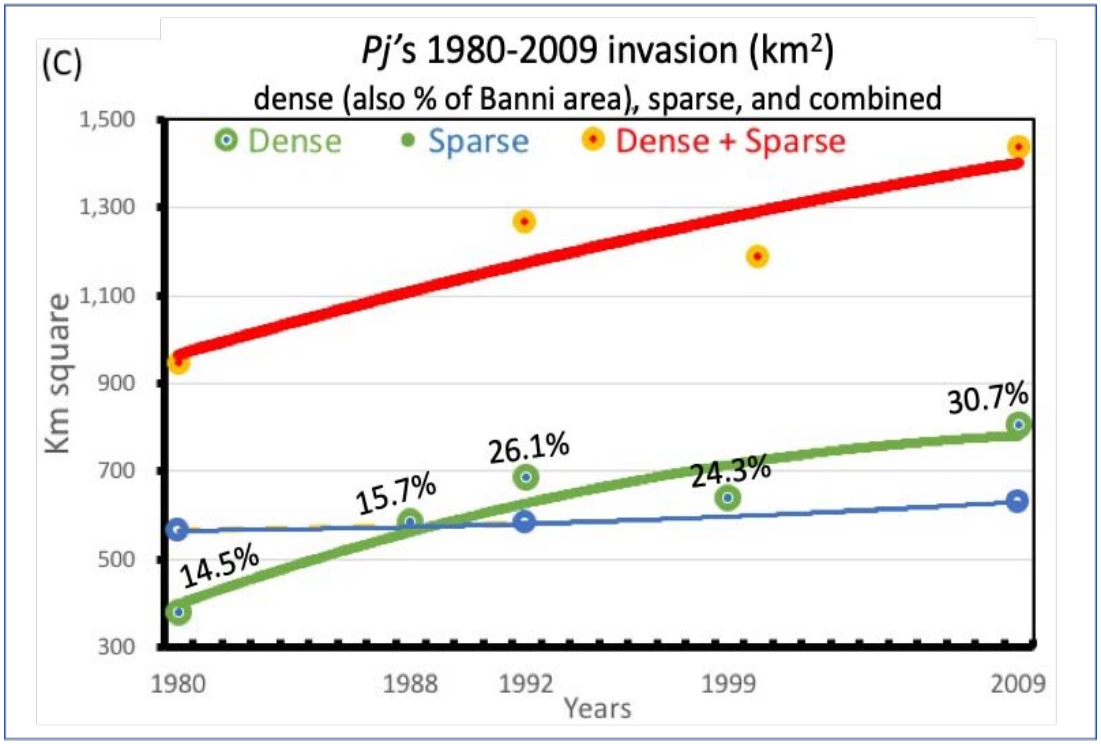
*(b) Image of 2009, black diagonal line marks the 1979 southern border of the areas masked. The Banni imageries of the years following that of 1979 are not masked.

Figure 6: Land cover classification of Banni' satellite images: (a) post-monsoon 1979; (b) post-monsoon 2009*

There are no records from the initial invasion stage during the first decade following the 1960s planting. Unfortunately, the *Pj* planting area (Fig. 6a) was masked for security reasons (see 2a) in the first satellite image of Banni, obtained in 1979. Nevertheless, 6.6% of the non-masked area, added to the recorded size of the planting area, suggested that by 1979 – a decade after its initial introduction – *Pj* was already established over nearly 20% of the Banni grassland. Thereafter, dense cover of *Pj* expanded at an average rate of 2,670 ha/year through the second decade (Jadhav *et al*., 1992), then gradually lessened to 1,664 ha/year by the fourth decade until, in 2009, it densely covered 30.7% of Banni (Fig. 6b, GUIDE, 2011), and sparsely covered another 24%.

This pattern of invasion illustrates how an area is at first sparsely invaded by young plants, and as they continue to grow and increase in density in that area, other areas become sparsely covered by new invaders. Thus, in the early stages of the invasion in the early 1980s, the areas of sparse distribution were more extensive than those of dominant distribution. But by 2009, *Pj* had attained dominance in most, but not all invaded areas, and the extent of Banni area covered with sparse *Pj* remained stable (Fig. 6c). Forty years after the end of its introduction period (from 1960 - 1970), *Pj* had invaded 55% of Banni (Fig 6b), transforming significant areas of grassland to woodland, and thus reliably deserving the title "transformer" invasive, *i.e.,* an *"invasive plant that changes the character, condition, form, or nature of ecosystems over substantial areas*" (Richardson *et al*., 2000).

However, in many areas of Banni, *Pj* distribution remained sparse (Fig. 6b, 6c). This is because the spatial invasion pattern was not that of a front advancing from the site of introduction, but rather of a patchy random distribution (Fig. 6b). *Pj* densely covered a substantial area in the heart of western Banni emerging from the introduction site, and two additional dense patches, at the western and southeastern edges of the grassland, ~5 km and ~20 km distant, respectively, from the larger area. Thus, the 2009 satellite image of Banni (Fig 6b) presents what appears to be a random pattern of *Pj* and grass patches embedded in a vegetation-barren, saline land cover. In fact, however, this "random" mix of patches of varying density, stable sparse patches, and a reduced invasion rate with time, mostly reflects the spatial variability of Banni's soil salinity – the major driver of Banni ecosystem change that affects both the invasive *Pj*, the indigenous grass cover, and their mutual interaction (see 3.c).



(Figure 6c): 1980-2009 invasion trends

Concurrent with *Pj*'s introduction in the early 1960s and its initial spread through the 1970s, Banni's inherent soil salinity was also increasing. From the first river damming in 1955 to the seventh in 1981, the freshwater flow into Banni continuously decreased, resulting in increased soil salinity year by year. This, with the inundations following the1965 road construction (see 3b), jointly initiated an emergent salinity surge, a process of transforming low-salinity lands to higher salinity within the <1 to >15 Mmhos/cm salinity range prior to the simultaneous *Pj* and salinity upsurges. Furthermore, the salinization trend, concurrent with the *Pj* invasion trend, has not been stable, but rather has been affected by intense rainfall oscillations. For example, from 1975 to 2014, annual rainfall ranged from 0 – 896 mm, with an average of 375 mm (CV=0.65), and there were13 very severe droughts[3]; the high rainfalls generated floods that reduced topsoil salinity, and the high freqency droughts increased it.

For example, from 1980-1992, areas of "extreme" (highest category) salinity, *Pj* and grass land covers all showed increasing trends. While the size of the highly saline lands fluctuated intensely with a 24% difference between lowest and highest area values, there was only a 12% and 8% difference in *Pj* and grass land covers, respectively. These oscillations were followed by intense rainfall oscillations (0- 657 mm/year) within this same period, which apparently affected the *Pj* and grass land cover size oscillations. The plant and rainfall oscillations were not fully concurrent, apparently due to the plants' delayed response to climate variabilities, often expressed by either flood or drought events (Fig. 7a).

[3] Measured in Rudramatha dam, 10 Km off Banni

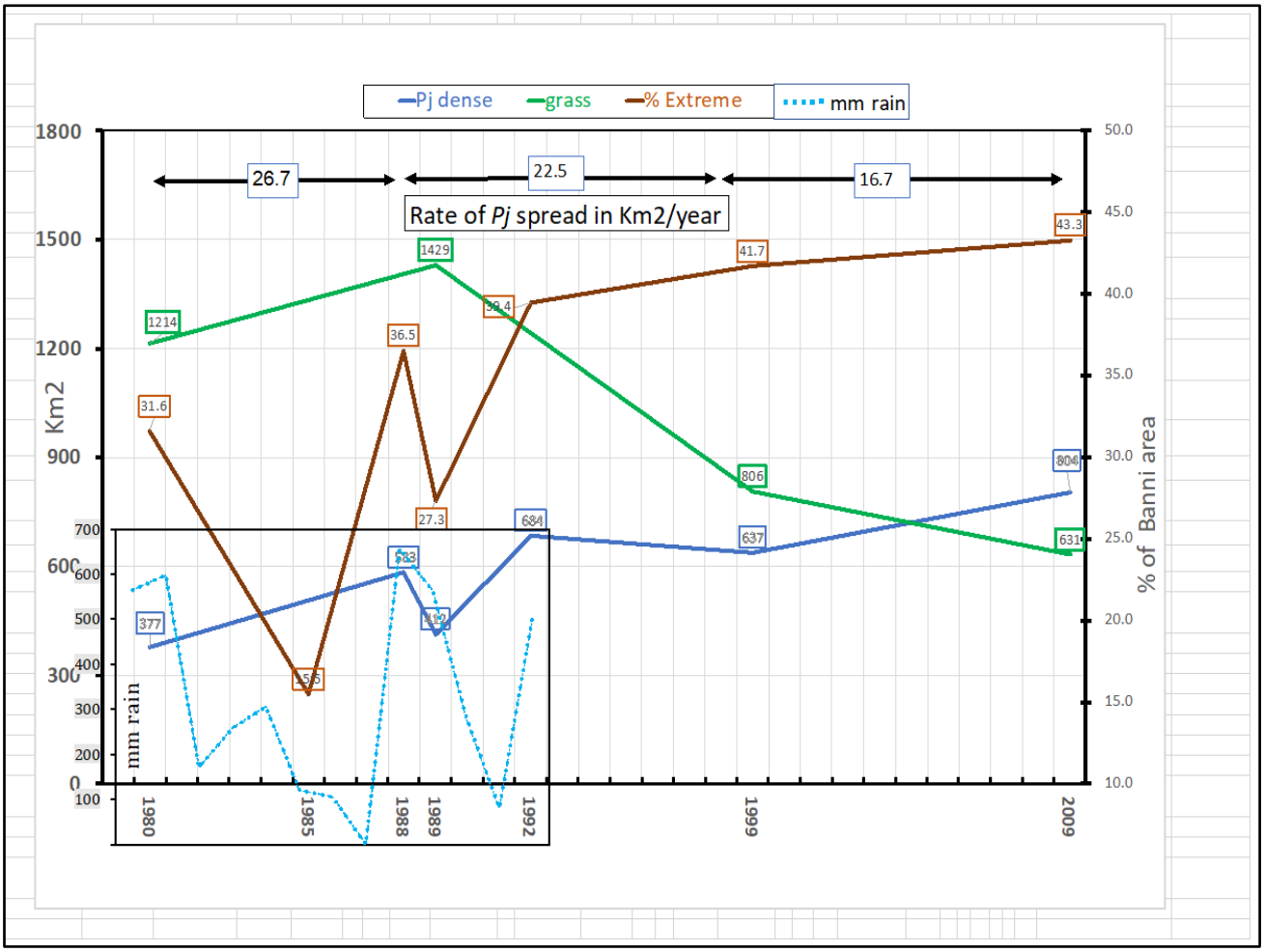


Figure 7a: Extreme salinity, Km^2 dense *Pj* & grass, mm rain in 1980 -1992

In the following period (1993-2009), the recorded oscillations are mild (perhaps due to a relatively small number of available observations), but the trends for the entire 1980-2009 period are clear (Fig. 7b): the intensely oscillating but overall increaseing salinity trend, rather than slowing *Pj*'s invasion rate, paradoxically advanced its relatively stable invasion, facilitated by the clearly decreasing grass land cover areas.

Hence, Banni's surge in soil salinity may have acted as double-edged sword – decreasing the indigenous grass land cover and empowering the competitive edge of the alien *Pj*, thus advancing its spread. Fig. 7a illustrates the relative contribution of the salinity surge and the *Pj* invasion surge to the grass distress in Banni. The barren area of extreme salinity continued to expand throughout the last decade of the 20th century and the first decade of the 21st century, from 715 Km^2 in 1989 to 1,134 Km^2 in 2009. This expansion coincided with a loss in productive grassland area of 798 km^2,while the extreme salinity soil, *i.e.,* land that lost its grass cover, "gained" only 419 km^2 (Table 2).This may indicate that the other 379 km^{2}of lost grass-covered area was transformed to *Pj* shrubland/woodland land cover. And indeed, during the same period, *Pj* range increased by 392km^2.

These data suggest that the loss of the grassland cover in Banni can be attributed approximately evenly 379 and 392 Km^2, to the increasing salinity and to its competitive exclusion by *Pj* (Table 2). The mechanism for these land cover exchange may be straightforward; i.e., the increased salinity paved the way for *Pj* to easily invade areas in which the grass cover had been reduced by the salinity surge. However, the initial *Pj* surge, from 26.7 Km^2/year of the 1980-1988 period, to 54 Km^2/year of 1988-1999 (or 48 Km^2/year of period 1988-1998, Jadhav et al., 1998; Jadhav et al., 1992) has not been maintained, but reduced to 16.7 Km^2 in the 1999-2009 following period.

Table 2: Attribution of the salinity surge and *Pj* invasion to grass cover decline – 1989-2009

	1989 area in Km²	2009 area in Km²	Difference area in Km²	Km² of grassland transformed to *Pj* cover*
Pj	412	804	+392 ≈	379
Grass	1429	631	-798	
Saline	715	1134	+419	

Nevertheless, most grass species, among them many palatable to livestock, are not totally outcompeted by *Pj*, as evidenced by their cover of spaces between neighbouring *Pj* trunks. Even though *Pj* litter scattered around the trunk is toxic, most of the grasses covering these spaces are out of the litter's toxicity range. Yet, as *Pj* plants become trees, they constitute a physical obstacle to livestock mobility such that the grass plants that evaded *Pj* competition and toxicity remain inaccessible to the livestock. Thus, the biological productivity, and hence the biomass, of *Pj* cover are higher than that of the grass land cover that it replaced, and even though this replacement allowed grass plants to survive, the economic biological productivity of the lands invaded by *Pj* declined significantly.

*The 798 kilometers of lost grass cover, minus the 419 increase in saline area kilometers, equals 379 kilometers, approximately equal to the 392kilometers gain in *Pj* land coverarea.

b) Pj driving ecosystem change, a contextual land degradation

The process of invasion of alien species, *Pj* included, frequently drives a process of ecosystem change that is often detrimental to the local people whose livelihoods depend on the services the ecosystem provides through its specific biodiversity components. Prior to *Pj*'s introduction, the Banni grassland's major ecosystem service provisioned forage for livestock – the mainstay of the Banni people – with a diversity of livestock-edible nutritious and palatable grass species. Banni's grassland ecosystem also contained woody plants typical to arid saline drylands: 24 shrub and 17 tree species, including *Suaeda*, *Ziziphus*, *Tamarix*, *Acacia* and even a *Prosopis* species – *P. cineraria*. But Banni was not a woodland ecosystem invaded by a woodland plant. Rather, *Pj* invaded a primarily grassland ecosystem, whose land was covered mostly by coarse and low perennial plant species - 6 sedge, 89 herb, and 37 grass species (GUIDE, 2011).

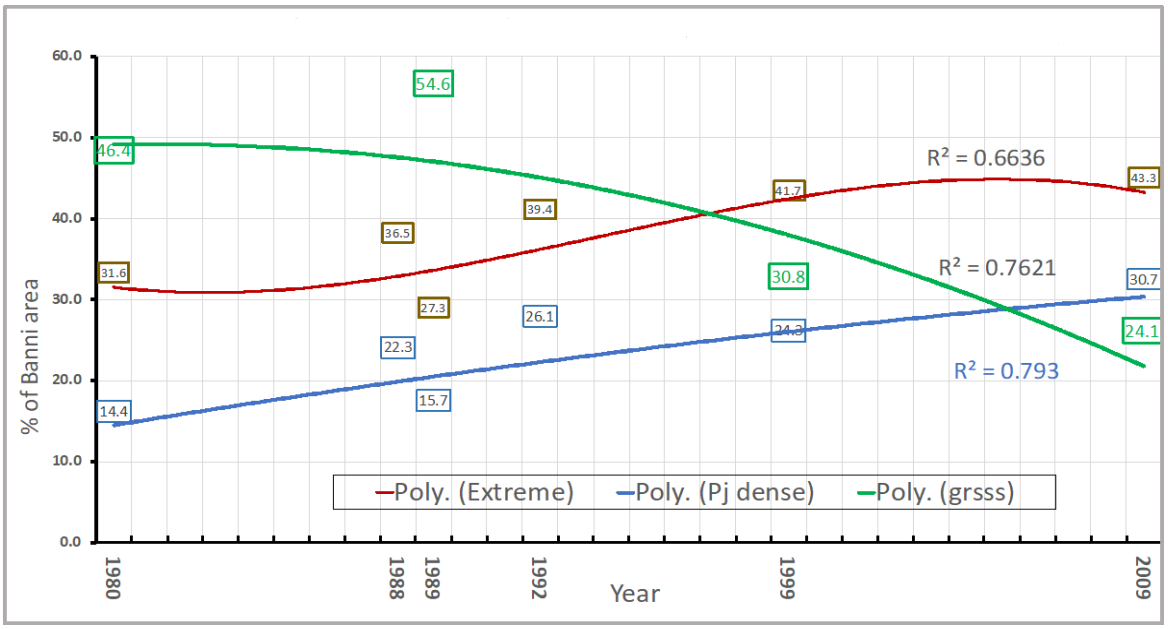


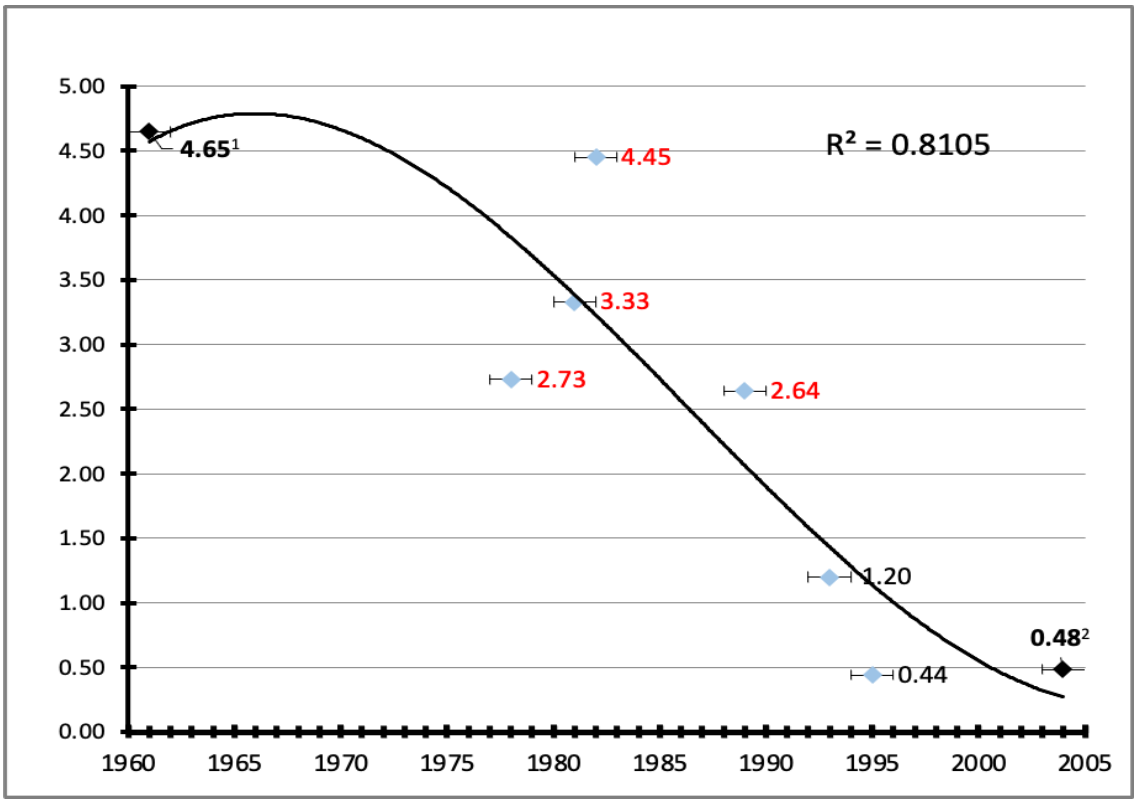
Figure 7b: Extreme salinity, dense Pj, grass in 1980 - 2009

Most of these species are palatable (Patel *et al*., 2012) but they accounted for only one-third of Banni's land-cover biomass (ton/ha); 10 grass species comprised 76%, and 8 herb species made up 33% (GUIDE, 2004). Furthermore, in 1965, the three dominant palatable grass species (*Dichanthium annulatum, Cynodon dactylon* and *Eleusine flagellifera*) constituted 32% of Banni's plant cover, and one non-palatable[4] grass species (*Desmostachya bipinnata*) accounted for 68% (Trivedi, 1965). Thus, prior to *Pj*'s invasion, even though much of Banni's grass land cover was not livestock-palatable, it nevertheless nicely supported the livelihood of its residents.

However, a decline in the grass and sedge species richness following *Pj*'sinvasion was detected when a 2012 survey did not record 12 of 41 grassland species registered at the same site 30 years earlier, in 1982 (Pandya and Sidha,1982, cited by Singh and Kumar, 1998). Furthermore, the grasland economic productivity, expressed in plant biomass annual yield (tons/ha of livestock-palatble species harvested from forage-protected plots), also declined, from 4.65 ton/ha in 1961 to 0.48 in 2004 (Trivedi, 1965; GUIDE, 2004; GUIDE 1998). The data clearly show a decline in grass yield (Fig. 8), even though four of the eight years surveyed had high rainfall (Saxena, 1993). This productivity declines apparently occurred in lands not yet densely invaded by *Pj,* but that were undergoing a concurrent salinization process, transforming low-salinity lands to high- or moderate salinity (Table 1, Fig. 6c). This can be attributed to the salinization process that reduced the grass density in these lands, facilitated by *Pj* invasion to these lands, but only in its initial sparse stage (Fig. 6c).

The reduced biological productivity of an economic value that detrimentally affects its users (in this case, the Banni people), and is driven by human interventions (in this case, river damming and *Pj* introduction) falls within the definition of "land degradation": "*land degradation means reduction or loss in …arid areas … of the biological or economic productivity of … range, pasture … resulting from processes … arising from human activities … such as …long term loss of natural vegetation*"; and when occurring in arid areas like Banni, it falls within the "desertification" definition: "*Desertification means land degradation in … arid areas resulting from … human activities …*" (Article 1, Use of Terms),United Nations Convention to Combat Desertification, UNCCD, no date).

[4] *Desmostachya* is grazed by buffalo only during the young stage, but the mature grass is non-palatable.



[1]Bhirandiyara village (Trivedi, 1965)
[2]GUIDE, 2004
◆ Data collected by Banni Development Agency (GUIDE, 1998)
4 values in red – ton/ha in a rainy year

Figure 8: Annual (mostly palatable) grass species productivity in tonnage per hectare

The Banni case can be also addressed in the context of land degradation/desertification process that is not attributed to climate variation and/or to land users' mismanagement, but to invasion of alien species.

The concurrent processes of soil salinization and *Pj* invasion that triggered the desertification and land degradation of Banni lands through gradual but steady transformation of its grassland ecosystem to one of shrub/woodland often leads to an ecosystem-service provision decline, or to a services trade-off. In Banni, not only did the livestock forage service decline, but its benefit – the income from bull/bullock sales – was challenged without a service trade-off. Demand for traction bulls dramatically declined and the grassland forage provision gradually lost its users/customers. As a result, the sale of Banni bulls for traction drastically declined.

c) *Exogenously-driven vicissitudes of Banni ecosystem and community*

The sale of Banni bulls for traction drastically declined when, by the beginning of the 1990s, about one-fourth of Banni was already under dense *Pj* cover (Fig 7a) and increasing salinity encroaching upon the grassland caused the loss of more than a quarter of Banni's pre-*Pj* invasion grassland yield (Fig. 5c, Fig. 8). These two processes coincided with a decrease in number of draught animals (80% of which were bullocks) from all over rural India, from 81 million in 1971-72 to 77 million in 1991-92 (RUTAG, 2015) -- an outcome of the "Green Revolution" initiated in the late 1960s, whose major benefits resulted in the 1970s and early1980s in substantial increase of agricultural production and in income of farmers (Parayil, 1992), encouraged by commercial banks to purchase tractors (RUTAG 2015), which "plowed the road out of poverty" (ICE, 2000) and replaced bulls, those having been nourished and prospered in Banni grassland included. Thus, while the decreasing flow of forage provision service of Banni ecosystem was driven by local environmental drivers of change, salinity and *Pj* surges, the reduced use of this service was driven by exogenous indirect technological, economic, social and cultural drivers of ecosystem change.

Note that even though the mainstay of most Banni herders was breeding and trading bulls, this cattle-based livelihood depended on foraging by both cows and bulls. Traditionally, the cow's prime function

was milk production for nourishing male offspring, while the function of the female offspring was to produce bulls. Herders, therefore, were hesitant to sell milk, concerned that once started, milk sales might escalate to where the amount of milk left after sales would not be enough for nourishing the calves and would lead to degradation of breed quality (Trivedi, 1965).

However, almost simultaneously with the decline in demand for bulls in India, the demand for cow milk soared, and Banni people, responding to the decline of bullock-based grassland-depended livelihood, adopted a cow milk-based grassland-dependent livelihood. This happened when India's "White Revolution", another country-wide scale economic and social driver, initiated by a Gujarati milk marketing cooperative by developing a nation-wide milk grid connecting rural producers with urban consumers of milk (Kurien, 2007), arrived at Banni in the mid 1980s. Then Banni cattle owners were included in the regional and national grid, and thereafter, this persuaded the herders, reluctant for centuries to sell milk, to initiate cow milk sales, such that by the 1990s milk delivery from Banni to a dairy became prominent.

This cultural-economic shift from a bull to milk economy brought about a shift in the Banni cattle/buffalo ratio, with the proportion of buffalo increasing from 15% to 45% to 64% in 1960, 1982 and 1992, respectively, and the cattle/buffalo ratio changing from 1/1.4 in 1977 to 1/2.5 in 2007 (Vijay Kumar et al., 2011). This trend, concomitant with those of increasing salinity level and *Pj* spread, occurred with cows of the Khunni buffalo (Banni breed too, Fig. 3) surpassing the Kankerj cattle cow, and milk superseding traction bulls as the major product of Banni grassland supporting the Banni people's livelihood. This was due to the relative advantage of buffalo over cattle expressed in the buffalo/cattle ratios of milk yield (7-12:1.7 litres/day), milk quality (6.5%:3.5% fat content), and annual income ($268: $154) (Geevan*et al.* 2003).

While Banni benefited from the White Revolution with its flourishing milk trade in the 1980s and 1990s, circumstances in rural India's Green Revolution changed, bringing a gradual restoration of the country's bull trade, including Banni's. This unanticipated outcome of the Green Revolution became evident when, during the 1990s, India's rural population growth apparently reached a tipping point, and, as a result, land holdings decreased to sizes inappropriate for tractor ploughing. This, and the overlong use of tractors increased soil compactness, diesel pollution and soil biodiversity loss that, together, reduced soil fertility (RUTAG, 2015). These initiated a gradual decline of tractor sales as of 1999 (ICE, 2000) and a bull trade recovery, such that in 2012, 13,000 to 15,000 Banni bullocks were sold (Bharwada and Mahajan, 2012).

Thus, with milk production peaking at 50,000-80,000 litters/day in 2015 (from 46,000 in 2008), and the revival of the bull trade, Banni's annual per capita income (based on the 2001 human population of 16,783) from milk and animal sales combined rose to $518-$791. Nevertheless, Banni's grassland-dependent livestock (cattle and buffalo)-based livelihood could not remain sustainable at the turn of the 20th century. Its 7-kg/animal/day grass consumption (Bhimaya and Ahuja, 1969) of Banni's 57,898 adult cattle units (ACU) in 2007 (an annual requirement of 192,994 tons), created a yearly deficit of 18,815 tons (GUIDE 2004). This consumption, defined as overgrazing -- leading to loss of vegetation cover, soil erosion, salinization and further expansion of *Pj* at the expense of grass covered lands – represents a classic land degradation/desertification scenario.

Added to grassland overgrazing, driven by the forage provisioning service having to support not only bullock but also milk sales, was the differential use of *Pj* pods and seeds (see 3c) by the two livestock species. As buffalo domination increased, so did *Pj* seed dispersal and rate of spread, and with this, Banni's rate of transformation from a grassland to woodland ecosystem.

This is because the alien *Pj* unexpectedly generated an additional provisioning service of Banni's ecosystem - *Pj* pods provision. The pods ripen during Banni's dry season, when the grass provisioning service declines. Consumption of *Pj* pods is seriously detrimental to cattle's health, productivity and survival (Tabosa *et al*., 2003; Kainaat and Jafri, 2015; Azeez and Chandra, 2009), whereas buffalo are resistant to the adverse health effects that cattle suffer. Thus, buffalo, rather than cattle, were the major livestock users of this service, and so *Pj* spread was further intensified. Furthermore, herders prefer buffalo over cattle not only because of their health resilience and better milk yield and quality, but also because the buffalo's principal diet during the dry period consisted of the *Suaeda* herbaceous plants that grow in high-salinity sites, which are believed to contribute to the buffalo's milk yield and fat percentage, but which cattle avoid.

Multiple factors advanced *Pj*'s invasion in Banni: the plant's adaptation for seed germination and spread (see 2c); vicissitudes driven by the Green and White Revolutions in the grassland ecosystem people's livelihoods; and changes in herd composition (see above) and number (increasing from 25,555 in 1977 to 60,417 in 2007, goats and sheep included (Vijay Kumar *et al*., 2011). The defecation rate of these animals, estimated at about 800,000 dung/day in different locations, drove an increase in *Pj* seed dispersal. Its spread was moderated by a herders-imposed restriction on the foraging range to village boundaries, given their drinking-water dependence. Although this restriction was relaxed in the early 1990's, in order to increase water availability for livestock outside the village limits, village residents punctured water pipelines constructed by the authorities for connecting Banni villages with a water

delivery system. Thus, development policy and cultural drivers further increased the livestock foraging range, and hence, the continued spread of *Pj*.

These effects of increasing negative grazing impact, combined with *Pj* seed dispersal and spread, led to a rapid transformation of Banni's ecosystem from a grassland to a *Pj* shrubland/woodland forest ecosystem (officially, Banni has a "forest" status). These, together with the loss of grassland provisioning services that supported both the milk and bullock sale livelihoods, constitute a loss of the biological economic productivity of Banni's land, exemplifying a continuous state of land degradation.

Thus, Banni residents have three options for maintaining a sustainable ecosystem-dependent livelihood and restoring their degraded lands: 1) attempt to block the current trends by fighting the alien invasive tree and restoring the grassland ecosystem's forage provisioning service; 2) explore the prevailing processes for identifying potential services of a *Pj* forest ecosystem that can generate novel benefits that would support new livelihoods; or 3) search for a balance between these two scenarios by managing Banni as a novel grassland/woodland mosaic ecosystem, with a richer diversity of ecosystem services that support a diverse set of acceptable and sustainable livelihoods, thereby forging an innovative restoration of Banni's land-degraded ecosystem.

V. Restoration - Transformative Change Response

a) *Pj biomass, a Banni ecosystem novel provisioning service*

The mounting damage and projected risk to Banni's traditional grassland-dependent livelihoods driven by *Pj* invasion brought Banni people to pressure the authorities responsible for introducing *Pj* to consider totally eradicating it from Banni (see IV 2 "option 1"). However, given the accumulated experiences from the Americas, Africa, Australia and other areas, it was clear that this option would be expensive, and, in fact, unattainable; *i.e.,* only some forms of control – not complete eradication – would be feasible (Pasiecznik *et al*., 2001). Thus, total eradication was impracticable; however, neither was the alternative of fully abandoning the traditional livelihoods an accepted solution.

This dead-end situation encouraged the emergence of a creative outlet: transforming *Pj* from the agent of Banni's ecosystem degradation to that of its ecosystem restoration, a solution paradoxically supported by *Pj*'s invasion adaptations (see III 3). To this was added another *Pj* attribute of potential demand – the plant's woody biomass, which when manufactured into charcoal, is an excellent firewood in high demand; it burns evenly, does not spark or smoke excessively, and has a high calorific value (4,200 Kcal/kg) – attributes shared with the tree's green branches following a short sun-drying period.

The potential demand for *Pj*'s biomass materialized when it became a source of domestic fuel for most of the rural households in India; in the last decade of the 20th century, *Pj* wood supplied about 70% of the domestic fuel of Indian drylands (2.5 tons/year/household). Prior to *Pj*'s invasion, Banni's people used wood of the land's few indigenous trees as source of domestic fuel. Later, triggered by the increased demand for domestic energy in the Kachchh region around Banni, *Pj* not only fully supported Banni people's domestic needs, but also gradually endowed them with a new livelihood, based on a novel Banni ecosystem service – a *Pj* biomass provisioning service, whose benefit is firewood, manufactured into charcoal.

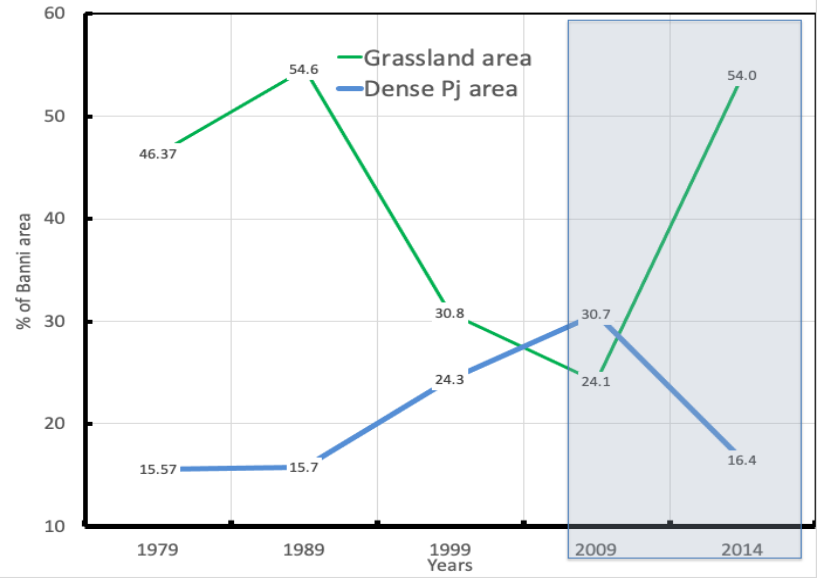


Figure 9: *Pj* and grass land cover percentages of Banni ares 1979 - 2014, effect of initial *Pj* harvesting 2009-2014

For example, after five years of harvesting all of the *Pj* trees covering 380 Km^2 of Banni, yielding an estimated 5,000 tons of charcoal (based on the 2010-2011 fiscal year's data), *Pj*'s cover of Banni decreased from 31% in 2009 to 16.4% in 2014. Areas from which this wood biomass was removed were simultaneously re-covered by grass, rather than by new *Pj* plants (Fig.9). This process constitutes a trade-off between the forage provisioning service of the grassland ecosystem with its milk and bulls' sale benefits, with a *Pj* biomass provisioning service and its charcoal sale benefit. Should this pace of *Pj* extraction continue, then the dense *Pj* remaining in 2014 would be converted to charcoal within the next five years – an apparently non-sustainable scenario requiring a change in Banni grassland management.

Based on Banni's dynamic mosaic of low-salinity land plots, tolerated by the indigenous grass vegetation, and others of high salinity, to which *Pj* is resistant (see iii c. and IV a.), a management plan of (1) removing *Pj* from the low-salinity plots, thus maintaining the flow of forage provisioning service of these plots, and (2), simultaneously applying a *Pj*-sustainable harvest regime in Banni's high-salinity plots, could alter *Pj*'s function as driver of land degradation/desertification, to one of a driver of land restoration and beyond. This would diversify the bundle of Banni's ecosystem services (grass forage plus *Pj* biomass), adding a new livelihood (charcoal) to the traditional ones (milk, bulls), rather than replacing them.

Thus, an alien invasive species that was a driver of an ecosystem service loss could also function as a biodiversity component underpinning the sustainable provision of a novel ecosystem service, once the demand for this new service emerges. Regarding the sustainability of this new *Pj* biomass provision, achieved – again paradoxically — by the plant's invasion adaptations of its salinity tolerance and deep-penetrating vertical root system. Together, these enable *Pj* to suck the highly brackish ground water of the Banni grassland and invest it in fast and vigorous post-cutting re-sprouting. Although cutting at ground level of *Pj* in an agroforestry system in Sudan slowed the re-sprout process, and their water use efficiency increased after pruning (El Fadl, 1997) in Banni, *Pj* trees cut at root level regenerated their removed biomass within 3-5 years (GUIDE, 2004, Harsh *et al.*, 1996). Regarding demand – *Pj* harvesting, responding to an increasing charcoal demand, was practiced during the 1980s though compromised by Banni's State Forest status making this practice illegal, until in 1988, when Gujarat State Forest Development Corporation (GSFDC) allowed selling Banni charcoal, but only to Kachchh residents.

b) Transformative change - livelihood diversification

Before exploring the Banni grassland management option (see V a), the economic benefit of a total *Pj* eradication as against maintaining the prevailing non-sustainable scenario (Fig.9) had been evaluated in 2016 by The Energy and Resources Institute (TERI) and also reported (Mathur & Sharma, 2018). Based on 23 years of data (1992-2015) this study presents the earnings of the pastoral (milk and livestock sales) and from *Pj* charcoal, up to the coming year 2030, using system dynamics simulations modelling of two Banni management options – maintaining current (*i.e.,* 2015) policies, versus total *Pj* eradication.

The variables feeding the model included: spread rate of *Pj*; sizes of livestock herds (*Pj* spread multipliers); life table variables of cattle and buffalo; land area under *Pj* and under palatable grass covers; effect of rainfall on grass productivity; external fodder input, pastoral outmigration; net income from livestock, milk, charcoal and from stress sales. The feedback loops and interactions among these variables governed the model dynamics and the results of its simulations.

These results indicate that maintaining current policies ("business as usual") will leads Banni grassland to severe fodder scarcity driven by grasscover contraction, while total *Pj* eradication would restore Banni's full grass cover and, by 2030, increase 2015's earnings by 62 per cent. Furthermore, a five-year delay in eradicating *Pj* would cause a 28 per cent loss of earnings. The study also estimates the cost of totally eradicating *Pj* during 2016 to 2030, at INR 6,000/ha[5], would be recovered by income from the restored grass cover, given that the prevailing ban on Banni *Pj* removal is lifted. In conclusion, attending the limitations of their research, Mathur and Sharma (2018) call for further research into the Banni grassland dynamics and development of policy tools for its sustainable management.

Furthermore, even though Mathur and Sharma (2018) elegantly and persuasively present *Pj* eradication for recovering the traditional Banni livelihood, considering *Pj*'s resilience and spread all over Kachchh (*i.e.* also all around Banni), keeping Banni clear of *Pj* is apparently not implementable. Yet, maintaining Banni's 1992-2015 management program is unacceptable. Therefore, given the determination of the Maldharis to maintain their tradition and culture on the one hand, and the current gradual spread of the charcoal livelihood in Banni on the other hand, a management for achieving sustainable coexistence of pastoral and charcoal livelihoods based on grass and *Pj* biomass, respectively, is to be considered.

Indeed, motivated by Banni grassland degradation process and the increasing demand for grass in Banni and beyond, GSFD initiated in 2010 a 20-year Banni Working Plan (BWP), some components of which specifically address the grassland-woodland (*i.e.*

[5] based on 300 m^2 *Pj* removal site executed by local NGO with community participation.

grass-*Pj*) interactions in Banni. The plan does not call for total eradication of *Pj*, but rather for annual harvesting of its sustainable yield from specific areas (~413.7 Km^2,16% of Banni) of its dense cover (*Pj* Working Circle areas), and uprooting it from areas (~673.2 Km^2, 26% of Banni) in which it is sparse, but the grass cover is dense (Grassland Working Circle areas). *Pj* plants removed from both areas are to be used for charcoal manufacturing, and, with implementation of two BWP practices, both areas combined would also enable sustainable livestock grass foraging. These practices are: 1) patches of good grass covering ≥ 5 ha within the *Pj* Working Circle would be uprooted at a frequency for preventing their regrowth, thus reducing competition and securing their forage provision flow; and 2) all *Pj* plants in the Grassland Working Circle area also would be uprooted, at the same frequency, to attain grass regrowth in significant areas of Banni. In the *Pj* Working Circle areas, where grass is scarce or absent, *Pj* would be removed rotationally in a regime that would secure a sustainable annual yield for supporting Banni's charcoal economy and emerging tradition.

To accomplish all of this, given that it takes 5 years for *Pj* regrowth to reach a size of economic value (Gurumurti *et al*., 1984; Kanzaria & Varshney, 1993; Tewari *et al*., 2001), a plot from which mature *Pj* plants have been removed can be re-harvested starting from the 6th year after its initial removal. Therefore, the *Pj* Working Circle has to be divided into units ('felling series'), each subdivided into 6 subunits (the 5 years of regrowth plus the year of first removal), of 50 ha each ('coupes'); *i.e.,* 138 ([41,370] / [50 ha x 6]) felling series', that jointly making the '*Pj* Working Circle'. Thereafter, in each of the five years following the year of removal of one sub-unit ('coupe'), *i.e*., a *Pj* cover of 50 ha, will be removed from one of the 'coupes'in each of the 'felling series'. Thus, a cumulative area of 6,895 ha (50 ha x 138 felling units) would generate an annual sustainable yield of *Pj* economic biomass, an annual contribution of the '*Pj* Working Circle' of Banni.

In addition, while adopting the BWP approach - conserving the Banni livestock livelihood by *Pj*'s sustainable harvesting that allows rotational regrowth of grass, thus supporting both livestock and charcoal livelihoods, GUIDE (Gujarat Institute of Desert Ecology) set to assess the potential of Banni ecosystem and people to achieve that livelihoods' coexistence. This by developing an algorithm (Algorithm 1) for calculating the size of Banni population that could be supported both sustainably (the size of 'block', a term parallel to BWP's 'coupe') and decently (the annual income) / (capita [charcoal worker]) by the current Banni land-cover.

Algorithm 1 first sets the constant values of: *Pj* density and biomass/ha; *Pj* biomass-charcoal conversion rate; man-days required for harvesting *Pj* ha and manufacturing it to kg of charcoal; number of days/year available for harvest and charcoal working; and number of *Pj* regrowth years.

The algorithm then attends the variables, first those required for calculating/projecting the harvested block size: Banni population size and number of charcoal households; number of persons/household; number of charcoal workers; and the cumulative size of dense *Pj* area available for harvesting. It then calculates/projects expected income (also compared with India's minimum monthly wage per capita), using the following variables: market price of charcoal/ton; *Pj* regrowth time (5 years), which together with the year of a block's first harvest, 6 blocks that are to be harvested at 5-year cycles for obtaining an annual sustainable yield. The algorithm thus enables projecting either the **number of charcoal households** that the area size for *Pj* harvesting could support, or the **size of *Pj* harvested area** that the available charcoal households can harvest.

Algorithm 1 presented here addresses a Banni scenario of 23,000 Banni population in 2011, where 20% of its household (percentage in Banni populations of years 2011-2017, Manjunatha, *et al*., 2019) include ~766 charcoal households, including 2,300 charcoal makers. This manpower can jointly harvest and manufacture charcoal from six blocks sized 2,760 ha each in a 240-day period of five successive years, (*i.e*., area of 16,560 ha, 21% of the ~80,000 ha of dense *Pj* land cover in year 2009). Given the sale cost of charcoal ton (5,000 INR in 2013), the annual value of charcoal harvested of that area (207 million INR), and the number of working days/years, the monthly income per worker (11,250 INR) is higher than the minimum monthly wage in India (9,750 in year 2020).

Algorithm 1. Calculating Banni charcoal-based livelihood's income from sustainably harvesting *Pj* land cover biomass

Constants for calculating 'block'[i] size and charcoal income

***Pj* density** (in dense *Pj* cover area) - **1,000 trees/ha**[2]

Biomass/mature tree - 65 kg/tree[3]

→ ***Pj* biomass/ha – 65 tons/ha**

Charcoal conversion rate - 23% of *Pj* biomass[4] **ton charcoal/ha – 15 ton/ha**

man-days **harvesting 10 trees – 1**

man-days **converting 10 harvested trees – 1**

→ **2 man-days for 10 trees work**

man-days **harvesting 1ha** trees – **(1,000 trees/ha)**/(10 tree/person/day) =**100 man-days**

man-day -- **making 1ha** trees – **(1,000 trees/ha)**/(10 tree/person/day) =**100 man-days**

man-days **converting *Pj* to** charcoal/**ha –200 man-days**

 # working-days/year – 240 days[5]

 # years for restoring harvested *Pj* area (*Pj* regrowth time) = 5 year[6]

 # years since the 1st 'block' harvested until it can be harvested again – (5+1) = 6 years

Variables for determining 'block' size

Banni **population size** (year 2011) - **23,000**[7] **persons**

 # persons/household – 6 persons, *i.e.* # Banni households (23,000/6) = 3,833 households

% of charcoal primary livelihood – 20%,[8] ***i.e.* 766 charcoal households x 6 = ~4,600 persons**

 # charcoal workers/household – 3 person-workers, *i.e.* (766 X 3) = 2,300 charcoal makers (CM)

Charcoal work – 2,300 persons working 240 days/year – (2,300 X 240) = 552,000 man-days

 # ha harvested – (552,000 man-days)/(200 man-days) = 2,760 ha → **'block' size**

***Pj* dense area for annual sustainable yield** of *Pj* biomass **– (block size) X (6 blocks) –**

– (2,760 ha) X (6 blocks) = 16,560 ha

Size of *Pj* dense area – 80,000 ha[9]

% of current area allocated for *Pj* management - (16,560/80,000) = 21% of *Pj* dense area

Variables for projecting income

Price (income)/1-ton charcoal – 5,000 INR[10] **(70 $US)**[11]

Income/1 ha - # tons charcoal yield/1 ha – (15-ton charcoal) X (5,000 INR) = 75,000 INR

Annual value of charcoal made of 1 **block –(75,000 INR) X (2,760 ha) = 207,000,000 INR)**

Annual income/1 Charcoal Maker (CM) – **(207,000,000 INR)/(2,300) =90,000 INR/CM/year**

Month income/1 CM – (90,000 **INR) / 8 month) = 11,250 INR/CM/month = 148 $US in year 2020**

Minimum India month wage - 9,750 INR/CM/month = ~ 130 $US in year 2019

Income/1 household/year (of 8 mo work) – (11,250 INR x 3 CMs) = 33,750 INR/household,

***i.e.* can support a 6-person family throughout a full year**

[1] rounding 45% of 2250 trees/ha (Gavali *et al*, 2009); (Panday *et al*, 2012)
[2] mean of 50-80 kg (not including roots) (Sood & Bhatia, 1993); (Khan *et al*. 1986)
[3] mean of 17-29 % (Hall *et al.*, 1982); (Pandey *et al.*, 2012)
[4] 125 days of the year, July to October monsoon period not suitable for charcoal work
[5] Gurmurti, *et al.*, 1984; Saxena *et al.*, 1993; Tewari *et al*., 2001
[6] rounded 23,065 persons
[7] years 2014-2017, (Manjunatha *et al.*, 2018)
[8] unit area for annual Pj harvesting
[9] year 2009 (GUIDE, 2010)
[10] Indian Rupees
[11] Yadama, 2013

For maintaining this satisfying scenario projected by Algorithm 1, Banni's demographic trend (for example, 8,724 to 23,065 people from 1961 to 2011), needs to be considered too. For that, projecting the dimensions of *Pj* land cover that would be sustainably harvested, or – projecting the Banni population size that could be sustainably supported by Banni *Pj* land cover, need to be assessed.

Algorithm 2. Projecting Banni population size sustainably supported by Banni *Pj* land cover

Variables (used in algorithm 1)

Pj 'block' size when **21% of Banni 2009 dense *Pj* area** harvested - **2,760** ha
charcoal maker (years 2014-2017) – **2,300** Charcoal makers
Pj area to be allocated for sustainable yield and fair income – (**2,760** X 6) =**16,560** ha
Available area for *Pj* harvesting – **80,000 ha** (year 2009 areas of dense *Pj* cover)

 # years between successive harvest – 6 years
4,600 persons of charcoal-based livelihood households (years 2014-2017)

Calculating population size using full size of 2009 *Pj* cover

Maximal *Pj* 'block' size – (**80,000/6** harvest years) = **13,333** ha

 # charcoal makers to be supported by Banni **maximal** *Pj* 'block' size –
- **(13,333 ha X 2,300 Charcoal makers) / (2,760 ha) = 11,112 Charcoal makers**

Average Banni **household size** - **6 persons** of which **3 are charcoal makers** -

 # household charcoal-based only – (11,112/3) = 3,704 households

Calculation results
(charcoal workers and others) = (3,704 X 6 persons) = **22,224 persons**
that the total Banni 2009 *Pj* dense area cover can support

~5 times higher than Algorithm 1 **projected** of **4,600 persons** -
- (20% of charcoal-based households in years 2014-2017)
If *Pj* sustainable harvest has been then implemented

For example (see Algorithm 2), the scenario of harvesting only 21% of Banni dense *Pj* area (in year 2009) decently supporting 766 charcoal-based Banni households, suggests that harvesting 13,333 ha (80,000 ha of dense *Pj*/6 blocks), the maximal *Pj* block size, would require 11,112 charcoal makers from 3,704 households, whose primary livelihood is charcoal-based. This makes a Banni population of 22,224 persons, a size close to its actual population size in year 2011 (~23,000 people). This projected population size is ~5 times bigger than the 4,600 persons, 20% of the Banni charcoal-based households of years 2014-2017 (given they would have implemented the sustainable harvest scheme spelled out in Algorithm 2).

Furthermore, the results of Algorithm 2 suggest that *Pj* alone can sustainably support populations of similar sizes, given that the 2009 *Pj* land cover size is maintained. Nevertheless, these charcoal-based projections are not a scenario of the livestock livelihood's demise. On the contrary, *Pj* rotational harvest would allow regrowth of grass whose accessibility to the livestock increases, as their foraging movement is no longer blocked by *Pj* thicket, at least for a period of 2-3 years following a *Pj* harvest. Also, sustainable yields of *Pj* charcoal and grass fodder would enable Banni population increase to sizes beyond that of 2011.

Thus, the transformative change scenario would comprise: charcoal workers and livestock herders become beneficiaries of sustainable flows of two different provisioning services of the Banni ecosystems; these Banni grassland ecosystem services are underpinned by two different plant biodiversity components – the indigenous grass species and a tree/shrub species, an invasive alien overgoing a naturalization process. However, for completing the change, field data on grass regrowth, foraging facilitation and rotational grass yield, still requires further research.

c) Past scenarios and the road forward

The previous chapters briefly touched on the Banni grassland conduct for generations until the 1960s *Pj* introduction, then addressed the undesirable repercussions of this introduction, followed by responses whose realization would require a transformative change, *i.e.,* doing things differently—not just a little more or less of something we're already doing. To fully achieve such a change requires more than bridging the knowledge gaps identified by Mathur and Sharma (2018) and by us (see Algortihm1). Still to be addressed are the environmental and anthropogenic drivers of change revealed throughout the 1980s, 1990s, and the 2000s, which are visually presented here (Fig. 10) by the meandering trajectory of Banni *Pj*'s charcoal extraction, functioning as an indicator of Banni's dynamic ecosystem and its users' interactions.

Up to the early 1980s, the Banni people sporadically cut *Pj* not only for domestic use but also for manufacturing charcoal and selling it to traders. Because this harvesting was illegal, its dimensions were not recorded. An additional incentive for *Pj* cutting emerged when the authorities recognized that, instead of protecting Banni grass land cover from exogenous salt transport (functioning as shelter belt, see iii b), and thus reducing land degradation, *Pj* negatively impacted this land cover, functioning as a driver of land degradation. Then, as of the early 1980s, a governmental "Banni Development Agency" (BDA), established in the late 1960s, initiated a "grassland development" project for restoring the grassland ecosystem. The BDA contracted private parties to cut down *Pj* in Banni, not only for encouraging grass protection, but mostly for charcoal manufacturing and selling. This triggered a surge of charcoal tonnage based on cut *Pj* biomass, legally removed from Banni, that peaked to 300,000 tons extracted in 1988 (Fig. 10).

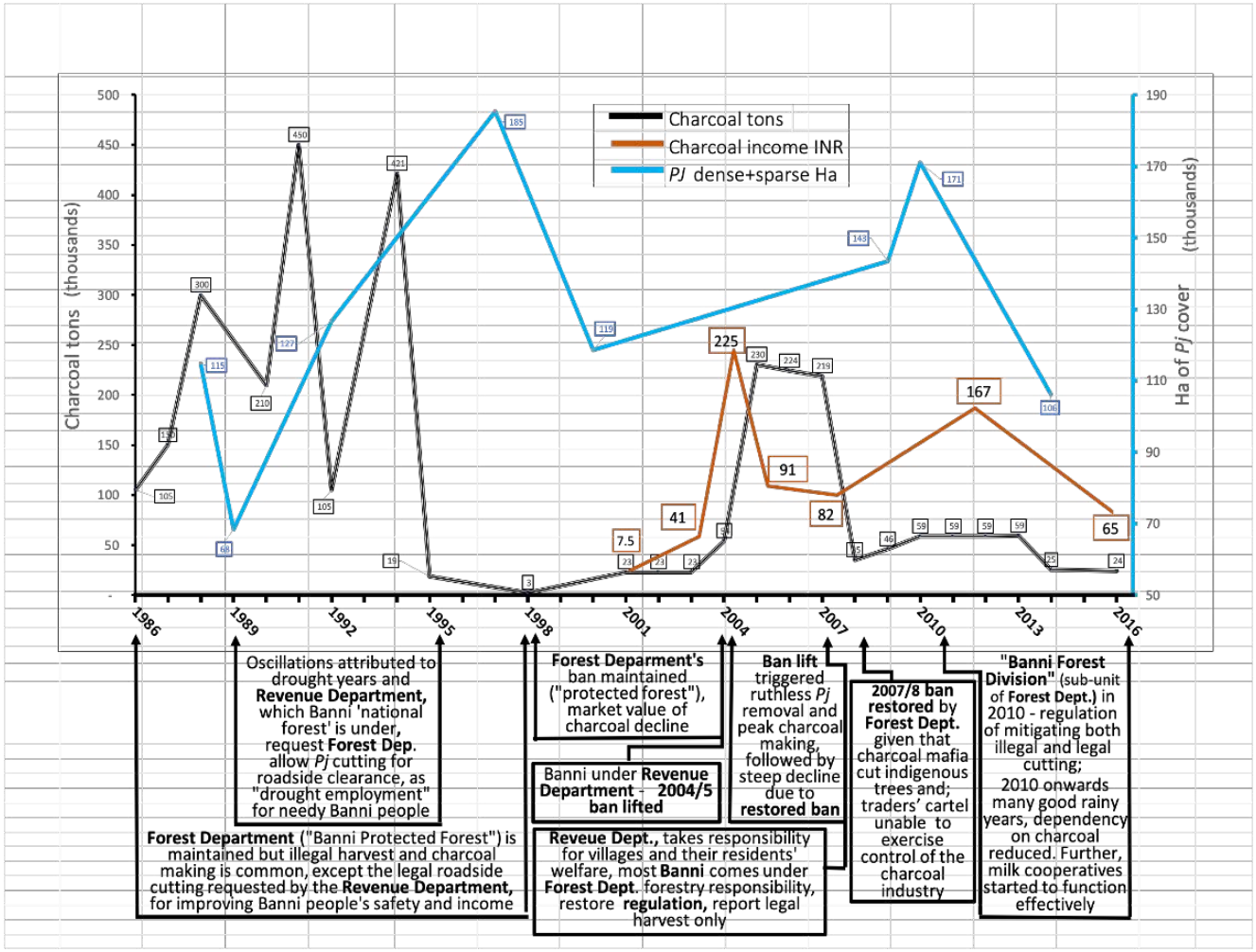


Figure 10: 1986 – 2016 *Pj* charcoal, tonnage and income, and Dense + Sparse *Pj* land cover trends

The *Pj* cutting surge continued until 1995, but this 10-year period experienced climatic oscillations, with drought years (>21% of 1975-2016 Banni mean annual rainfall), each followed by an extremely high rainfall year (<73% of mean). These climate-driven oscillations were reflected in *Pj* availability and charcoal production, and also caused grass reduction that resulted in income loss to Banni people. The latter triggered a *Pj*-cutting policy change when the Revenue Department -- the government authority responsible for Banni, with its social-economic leaning, requested that the Forest Department, which had outlawed *Pj* cutting in accord with its role in protecting national forests, will reverse the ban and legalize *Pj* cutting. This ban lift enabled roadside clearance of *Pj* cover, a "drought employment" for needy Banni people, which covered their drought years' economic losses, and improved travel safety as well. The rainfall variation and policy changes are expressed by the 1986-1995 oscillations in charcoal production: a range of 150-450 charcoal tons removed in 1987 and 1991, respectively (Fig. 10).

These were followed by restoration of the Forest Department's ban in 1995. Lasting until 2004, it marked the period of lowest charcoal production (~20,000 ton/year, Fig. 10). But in 2004, the Revenue Department lifted the *Pj* cutting ban, triggering a ruthless *Pj* removal, expressed in charcoal manufacturing and income peaks (Fig 10). However, this was soon followed by a steep decline as of 2007/8, when the Forest Department re-instituted the ban in response to the emergence of a charcoal mafia, which was cutting indigenous Banni trees as well as *Pj*, and also to the emerging charcoal cartel's failure to control the charcoal industry. This restored ban was expressed in low charcoal tonnage (25-59 ton/year), followed by declining charcoal market values and income from 2008 to 2016. This regulation to mitigate both illegal and legal *Pj* cutting was implemented in 2010, with the establishment of the Forest Department's Banni Forest Division; from that time to 2016, 24-25 tons of charcoal were produced annually (Fig.10).

In conclusion, the charcoal trends shown in Fig. 10 depended not only on the grassland ecosystem's natural processes and their responses to the environmental drivers of salinity and rainfall, but also on government policy variations. These are rooted in the strict (though not updated) legal status of Banni as a "national forest", but one in which regulations may be relaxed when it is determined that circumstances affecting the well-being of the locals and the practices for managing their ecosystem require intervention. Moreover, the rather low but relatively stable rate of charcoal production and its support of Banni people's livelihood throughout the second decade of the 21st century has been maintained not only by regulation and enforcement, but by its role in a novel emerging socio-economic trend that likely will moderate the Banni people's dependency on its grassland ecosystem provisioning services and their plant products (grass forage for milk and *Pj* biomass for charcoal). It is based on materialization of potential services of the grassland ecosystem never used before – the Banni ecosystem cultural services.

Banni is kind of a terrestrial island away from India's bustling cities - a mid-desert productive greenery of diverse land covers (trees, shrubs and herbs, water bodies), inhabited by a visually and vocally tangible biodiversity of birds (262 species, Koladiya *et al*., 2016), mammals, bees and butterflies (among them 'charismatic'), and by indigenous human communities of rich culture and skills adapted to life in this unique ecosystem. These attributes of the Banni ecosystem enrich it by adding to its already used ecosystem service bundle, a potential cultural service that would materialize once the demand for it has been created. Globalization and other cultural-socioeconomic processes have apparently already created this demand, seen in the appearance of bhunga huts(a traditional mud structure) and tourism in Banni in the first decades of the 21st century. Added to this are cultural attractions, such as the "white desert" festival and, with support of the Gujarat Tourist Department, a trend in homestay/ecotourism, currently with over 200 tent houses in Banni. This suggests that the income generated by the Banni grassland's cultural services even at present would slightly lessen the people's critical dependence on its provisioning services (fodder and *Pj* biomass).

Returning to the road forward, it should be noted that since its initiation in 2010, the 20-year BWP has been engaged in circles not addressed in this paper, *e.g.*, Improvement (plantations, etc.) and Wildlife (habitats) circles. More relevant, the BWP's Grassland Working Circle has, already advanced grassland restoration throughout its first decade, work that will likely continue, together with work in the *Pj* working circle, as planned, until 2030. Then, being a longstanding document BWP will function, with some additional amendments as per the scenario in 2030.

Furthermore, all BWP working plan areas are to be overlapped by unique working circle – the Joint Forest Management (JFM) Working Circle, constituted to provide active participation of local people in the management of Banni. The JFM involves local villagers working with forest officials, guided by a joint committee of the two groups. Presently the JFM is active only in the Grassland Circle, but it is expected to work for a mutually agreed upon program of conservation, restoration and management, along with regulating the collection of minor forest products and *Pj* removal (where needed), as well as charcoal manufacture. With this, it is likely that once the JFM has become more active, the sustainable harvest algorithms (see V b) would be promoted for sustained implementation. Thereby, a diversity of Banni sustainable livelihoods can be maintained, based on the grassland's bundle of ecosystem services, underpinned by an invasive alien that has become a naturalized biodiversity component of the Banni grassland ecosystem.

VI. Banni Land Degradation and Restoration

a) Pj and land degradation

This paper examines approximately 60 years of the Banni Grassland, an ecosystem at the edge of the Asian Thar desert, which hosts and supports an indigenous human community, modulated by environmental- and human-generated vicissitudes. We spotlighted the role of a shrub/tree invasive alien, *Prosopis juliflora*, in the dynamics of this unique and intriguing human-environment system. For this, we reviewed literature addressing rangelands and their people, how they responded to challenges of dryland climatic conditions, land degradation, and alien species' invasions, and the efficacy of the responses. Some of the literature focused on *Pj* invasions mainly in Africa and India, and others looked specifically at Banni.

Most reports point to knowledge gaps that require bridging through further research. For example: "*Research is needed to identify novel solutions to aid the dilemma of management and contentious issues regarding invasive Prosopis globally*" (Zachariades *et al*., 2011); and "…*dilemmas and conflicts of interest among stakeholders involved in the management of P. juliflora need to be thoroughly investigated*" (Ayanu *et al*., 2015). For our review to incentivize further studes to bridge the knowledge gaps regarding grasslands whose lands experience degradation, invasion of alien species and restoration, we used an integrated conceptualization of these processes by streamlining them into the

Biodiversity and Ecosystem Services (MEA[6]) and Land Degradation and Restoration (IPBES' LDRA[7]). This approach is presented here as the Conceptual Framework of Banni Grassland Socio-ecosystem, addressing Banni ecosystem dynamics in three stages, outlined in Figures 11a, 11b, and 11c, respectively, as follows: Prior to *Pj* introduction; *Pj* invasion – grass-land degradation; and *Pj* naturalization – socio-ecological system restoration/rehabilitation.

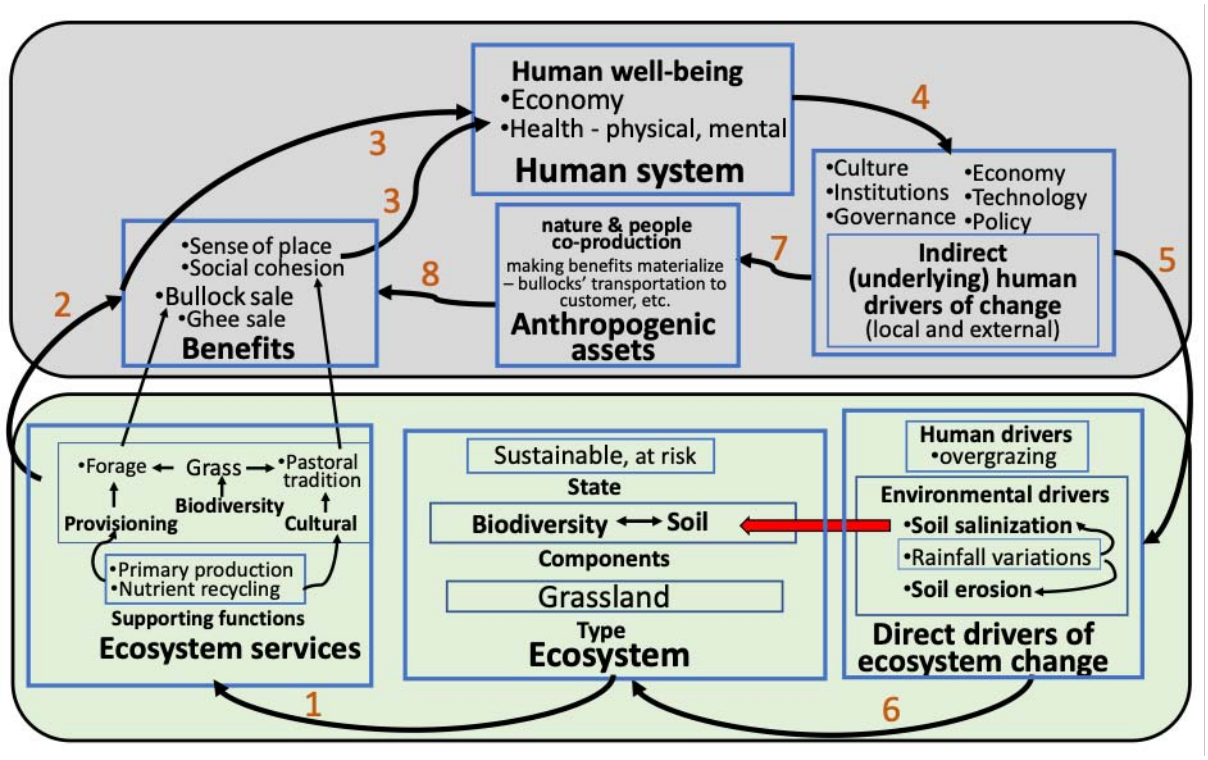


Figure 11a: Conceptual Framework of Banni Grassland Socio-ecosystem – Prior to *Pj* Introduction*

Adapted IPBES Conceptual Framework (Diaz *et al*., 2015; IPBES, 2018) - boxes and arrows denote the elements of the Ecosystem and the Human system and their links indicated by numbered arrow are described in the main text.

In Fig. 11a, the boxes in the lower (green) rectangle represent the ecological system landscape[8] and those in the upper (gray) rectangle represent the **human system** landscape. Together, they function as a unified **socio-ecosystem**, with their linkages depicted by an ellipse of arrows starting from the bottom center **Ecosystem** box, leading to the top center **Human system** box (arrows 1,2,3), and back to the Ecosystem Box (arrows 4,5,6). An explanation of the contents of the boxes follows, starting with the **Ecosystem** Box.

A desert land blessed with a perennial grass cover, Banni is categorized as a **grassland ecosystem** – an **Ecosystem Type** common in drylands. Its substantial interacting **components**, **soil** and **biodiversity**– comprise Banni's natural capital, generating a flow of **Ecosystem services** (arrow 1). This flow is supported by ecosystem **supporting functions –primary production** and **nutrient recycling**. These functions create and maintain the biomass of Banni grass species, a component of Banni **biodiversity**, underpinning **provisioning** and **cultural** services delivering a flow of **Benefits**, thus linking the natural ecosystem to the human system (arrow 2). These benefits supplied by the ecosystem support and strengthen the **well-being** of Banni people (arrow 3).The major benefit of the grass forage provisioning service is feeding the Banni livestock, thus supporting the "Banni bullock" sale as the mainstay of Banni people prior to *Pj*'s introduction, to which sale of ghee, milk product of buffalo (mainly) and cattle, locally very popular. These benefits constitute the economy and health components of Banni people's well-being. Furthermore, the Banni pastoral tradition of breeding bulls is embedded in the

[6] (Millennium Ecosystem Assessment, 2003) - Ecosystem services generate benefits that humans derive from ecosystems. They are grouped as: supporting services (necessary for the production of other ecosystem services *e.g.*, soil formation, photosynthesis and nutrient cycling); provisioning services (products *e.g.*, food, fibre and water); regulating services (processes - climate stabilization, erosion regulation, and pollination); and cultural services (non-material benefits from ecosystems - spiritual fulfilment, cognitive development and recreation).

[7] The Land Degradation and Restoration Assessment (LDRA) of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES, 2018).

[8] This use of *landscape* has nothing to do with the physical world and it is trickling into context such as 'an operational framework, incorporating an integrated socio-ecological landscape approach' (IPBES, 2018).

culture of the Banni herders, a culture based on the grass cover of the Banni ecosystem. In the ecosystem services context, these are the Banni grassland ecosystem's cultural services - non-material benefits that are often expressed in people's **sense of place** and **social cohesion**, and contribute to both mental and physical health, all components of **human well-being** (**Human system box**).

The flow of the provisioning service is subject to drivers of ecosystem change. These are often initiated by indirect, underlying drivers generated by people and elicited by the state and/or changes in the well-being of people, local and beyond (arrow 4). Shown in the **Human drivers of ecosystem change** box are the most Banni-relevant - policy, governance and economy, that are indirect, underlying human drivers of change; *i.e.*, the Banni human system affecting its ecosystem (arrow 5). These include the human-dependent sporadic **overgrazing** in Banni, and interlinked environmental drivers, such as **rainfall variations:** *i.e.,* severe rainstorms and floods directly cause **soil erosion**, and droughts increase soil erosion, while rainstorms mitigate the **soil salinization** driver underpinned by Banni inherent underground saline water, affecting plant biodiversity (red arrow parallel to arrow 6). This driver of ecosystem change endangers the Banni grassland ecosystem's **state** (**Ecosystem** box, top), though its state prior to *Pj* introduction has been categorized as sustainable; *i.e.,* amply maintaining the **well-being** of Banni people, but always at risk of amelioration due to the soil salinization potential threat.

Returning to the **Indirect drivers'** box, intangibles, such as **institutions**, **governance** and **technology** are linked (arrow 7) to education and local knowledge systems, collectively designated "**Anthropogenic assets**", which are instrumental in materializing and making accessible the ecosystem-derived benefits that contribute to the people's well-being, and represent an ecosystem and people co-production of benefits (arrows 8 and 3). For example, the breeding and sale of bullocks depend on veterinary services and local knowledge if this benefit is to contribute to the sustainability of Banni people's well-being. Before leaving Fig. 11a we return to the **Ecosystem** box and its 'sustainable' **state,** since natural processes, *i.e.,* seasonal rivers' freshwater flow through Banni, reduce Banni's prevailing inherent salinity, thereby maintaining it as a grassland. But this sustainability is at risk, given that the 'soil salinization' direct driver may become active, and put at risk the striving for **human well-being** (arrows 3).

With this in mind, we move forward in time, to Fig. 11b – the socio-ecosystem dynamics triggered by *Pj*'s introduction (see IV b) and subsequent invasion. Here we start with the **Human system** box, affected by water shortage (in this case, off Banni), prompting (arrow 1) a policy of river damming (see III b), a process that intensifies soil salinization, and thereby transforms an **environmental** direct driver of soil salinization to a **human** one (Direct drivers' box of Figures 11a and 11b, respectively). This is amplified by the **indirect human drivers** of ecosystem change (**Indirect drivers** Box, arrow 2) affecting the two components of the ecosystem (arrow 3) – **soil,** whose salinity impacts **biodiversity**.

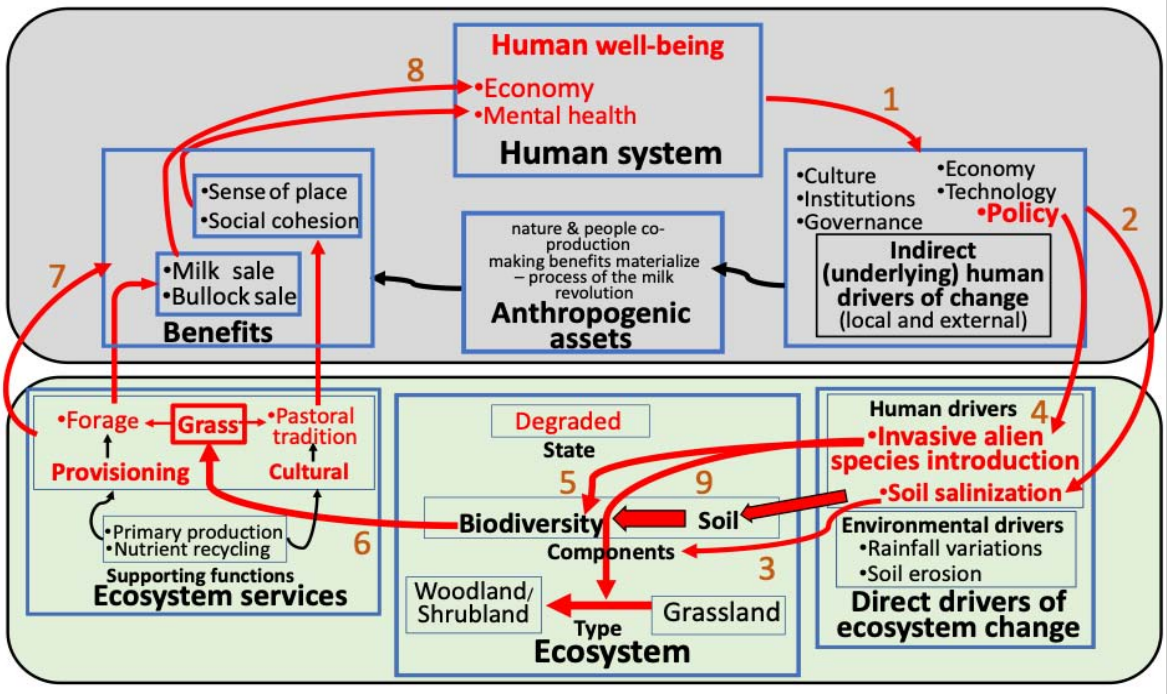


Figure 11b: Conceptual Framework of Banni Grassland Socio-ecosystem – *Pj* Invasion – Grass-Land Degradation

The increased salinity and the awareness of its expected negative impact on Banni's **human well-being** (**Human system** box) triggered a second policy initiative – the introduction to Banni of an invasive alien, *Pj* (arrow 4), which functioned as a direct human driver of ecosystem change. Within a short time, the invasion of the alien plant impacted the ecosystem's **biodiversity** components (arrows 5) by outcompeting the **Grass** biodiversity component and reducing its land cover in Banni (see III c). The impact on the grass cover that underpins the supply of the **provisioning** and **cultural ecosystem services** (arrow 6), conferred the title **"degraded"** on the ecosystem's **State** (top of **Ecosystem** box). The degradation impacted the services' benefits (arrow 7) (which at that time also included milk sale [See IV c]), and thus created potential harm to the **well-being** of the Banni people (arrows 8), *i.e.*, degradation of the human system in response to the ecosystem degradation. Furthermore, the grass **degradation** process enabled a gradual *Pj* grass cover replacement through a process of "**ecosystem transformation**" from a grassland ecosystem to a *Pj* woodland/shrubland ecosystem (Arrow 9), which in turn led to a further ecosystem transformation (see Fig. 11c).

Thus, Fig. 11b presents the 'invasive alien species' as a direct driver of degradation processes, often addressed in the context of land degradation – eighth in the list of **land degradation** drivers and defined as *"the state of land which results from the persistent decline or loss in biodiversity and ecosystem functions and services"* (IPBES, 2018), or *"persistent reduction in the capacity of ecosystems to supply services"* (Millennium Ecosystem Assessment, 2005), either through biodiversity loss, or by **transformation** to a derived ecosystem type" (IPBES, 2018). Hence, given that the **degraded** title is assigned to **state** of a grass-**land** ecosystem, this state of Banni grassland can qualify as **'land degradation'**, and since Banni land is climatically classified as arid dryland, this land degradation process also qualifies as **desertification** (see IV b).

b) Pj naturalization and land restoration

Here we move forward in time from the *Pj* invasion process and the grassland degraded state (Fig. 11b), to *Pj* **naturalization** and the socio-ecosystem **restoration** processes (Fig. 11c). Although some confusion persists in the literature regarding 'naturalization' *vs* 'invasion' in alien and/or invasive plant species' stages, it is proposed that naturalization starts "when barriers to survival and then barriers to regular reproduction are overcome" (Richardson *et al*., 2000). However, earlier definitions of a naturalized species, *e.g.,* "Introduced from another region but growing, reproducing and maintaining itself in competition with the native vegetation" (Walker, 1989), and "established extensively amongst native vegetation so as to **appear native"** (Clement & Foster, 1994), fit well with *Pj*'s status as shown in the **Direct drivers of ecosystem change** (box of Fig. 11c).

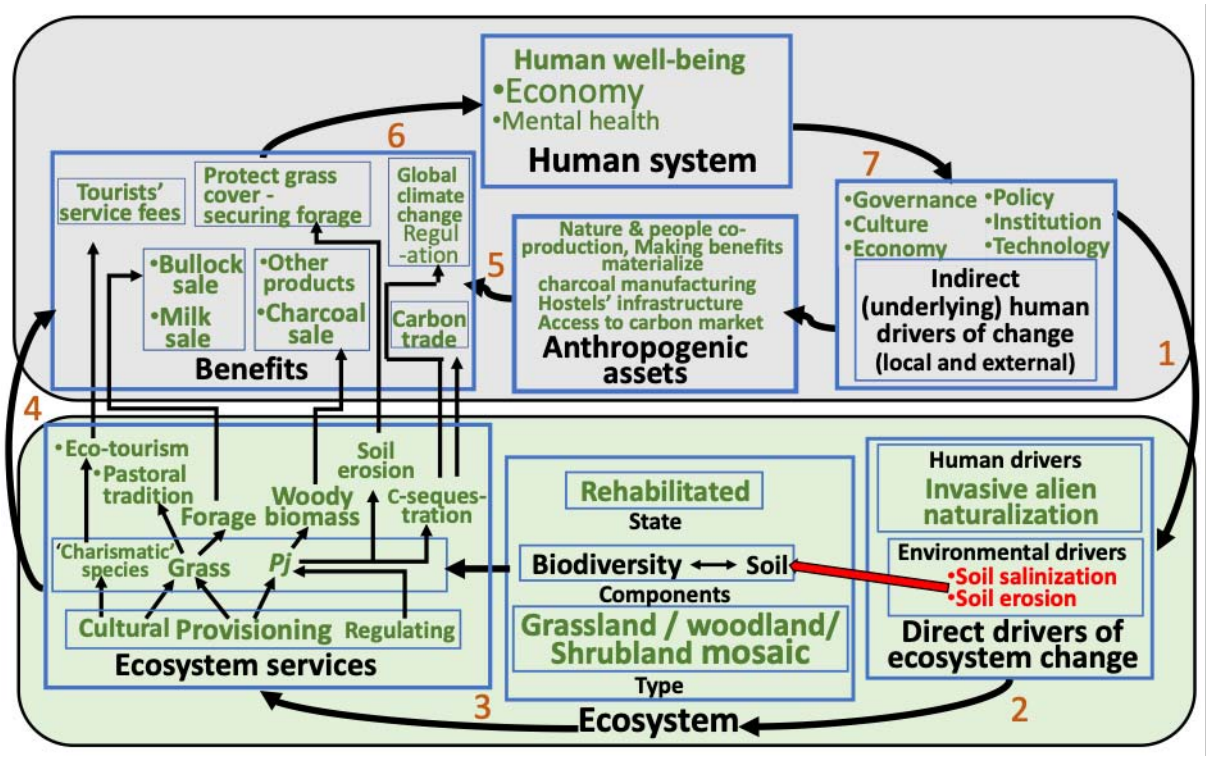


Figure 11c: Conceptual Framework of Banni Grassland Socio-ecosystem – *Pj* naturalization, socio-ecosystem restoration/rehabilitation

Furthermore, following the linguistic definition of naturalization – "the **admittance** of a foreigner to the citizenship of a country" (Oxford languages, https://languages.oup.com/), and given that the Banni authorities promoted and the community adopted, the **'control by use'** approach (Van Wilgen *et al*., 2012; Shackleton *et al*., 2014) rather than the *Pj* eradication one (see V a & V b), the naturalization stage of *Pj* can be defined as "**admittance** of alien invasive species to, and acceptance by, Banni's indigenous **socio-ecological system**". This, and given that already *"in several areas of South India, Prosopis trees and shrubs have become naturalized"* (Pasiecznik *et. al.,* 2001), *Pj* has already been naturalized in Banni too. And, it functions as an **Indirect driver** (arrow 1), converting the **Direct driver** of degradation to a driver of **rehabilitation** (arrow 2),a component/state of **Restoration** that falls short of fully restoring the grassland ecosystem to its pre-degradation state (IPBES, 2018). Thus, the degraded Banni grassland ecosystem, expressed in reduced land areas of grass cover, has not been restored to the pre-invasion land size of grass cover, but has been rehabilitated to function as a mosaic of **grassland/ woodland/shrubland** ecosystem, jointly covering the pre-invasion Banni grassland ecosystem area, now in a **rehabilitated** state (top of **Ecosystem** box).

This diversified mosaic of grass patches, dense *Pj* tree patches and sparse *Pj* shrub (young *Pj* plants) patches constitutes a novel grassland/woodland/ shrubland ecosystem supplying a diversified bundle of ecosystem services (Arrow 3). Most important for the Banni people's well-being is the provisioning service, now underpinned by two biodiversity components: an herbaceous plant community, many of which are livestock-palatable (see IV b), and labelled here as "grass"; and a biodiversity component comprising the by now naturalized *Pj* plant –trees and shrubs of all ages and densities. Thus, the novel ecosystem supplies two ecosystem provisioning services – grass and *Pj* products, livestock forage, and woody biomass, respectively. The benefits of each provisioning service (Arrow 4) include milk, a critical product enabling bulls to be sold as truck bullocks, and milk sale for human consumption; and *Pj* woody biomass for manufacture and sale of charcoal as an energy source.

Furthermore, the two biodiversity components, grass and *Pj*, underpin additional ecosystem services, cultural and regulating, respectively. Since the pastoral livelihood of the herders is based on the ecosystem's grass cover that nurtured their **pastoral tradition** which they cherish, it qualifies as one of the nonmaterial benefits from ecosystems, known as 'cultural services'. Grass, in addition to its forage function, is also valued for its green landscape, contrasting with the surrounding desert. This, together with other biodiversity components of Banni grassland, especially the 'charismatic' species (*e.g.,* Houbara, Flamingo, Chinkara [Indian gazelle], Desert fox and others), provides another cultural service, eco-tourism (see V c), which benefits tourists with recreation, relaxation and spiritual fulfilment options, and benefits Banni people with tourist fees, an income added to that of their sales of milk and charcoal products.

In addition, Banni's biodiversity underpins a bundle of regulating services, such as regulation of soil erosion caused by intense rainfall and wind storms, as well as livestock trampling and overgrazing. This erosion is mitigated by the below- and above-ground Banni land cover of grass and of *Pj* plants, where the share of *Pj* to the regulating service is significant, due to its below-ground root systems and the above-ground cover of its woody canopy (*Pj* was introduced in the 70s to Ethiopia for addressing soil erosion problems, [Shiferaw *et al.,* 2004]). Furthermore, *Pj*'s role in the soil erosion regulation service made the plant an agent of full restoration of Banni's economic biological productivity (not just rehabilitation). This in specific land areas where this productivity had been lost due to human induced intensification of their soil salinity, *i.e.,* areas of land degradation, what makes them ones whose biological productivity is restorable.

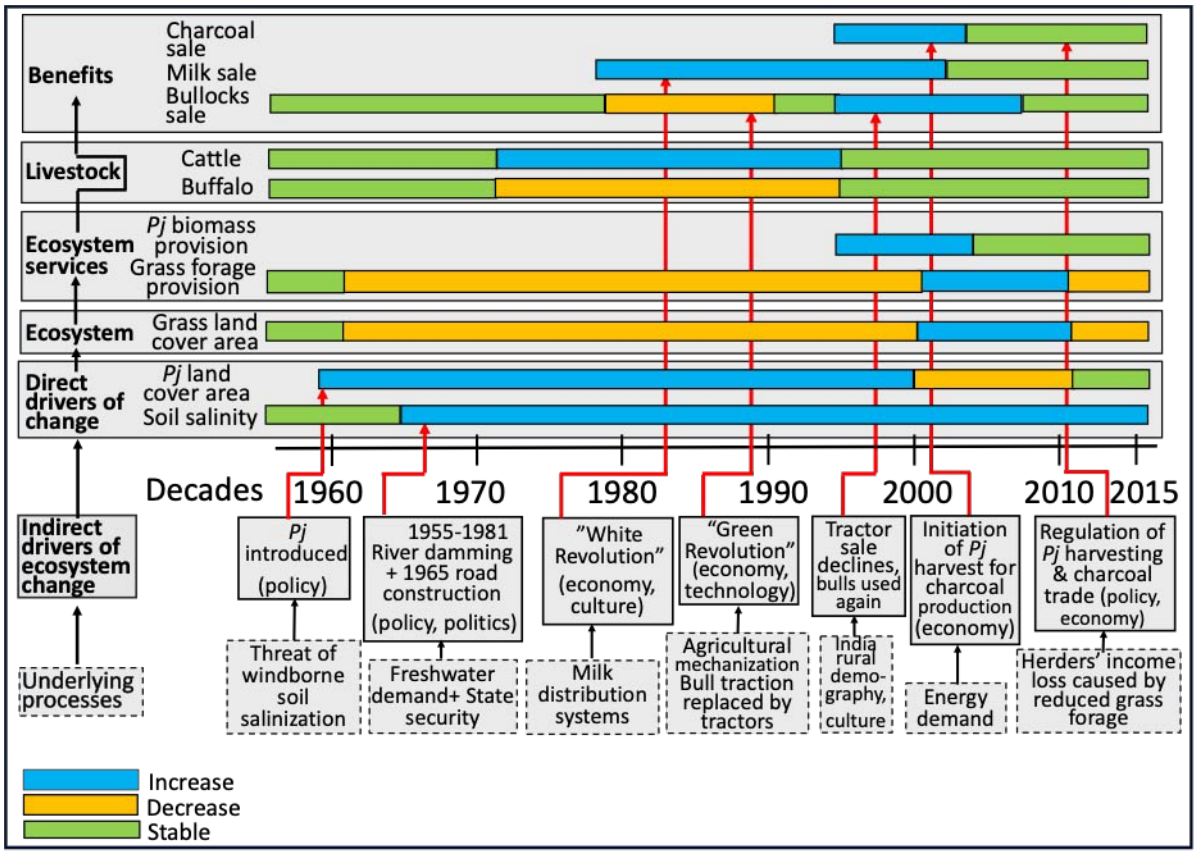
This degradation/restoration process occurs in Banni land areas where inherent high salinity levels have been transformed to an extreme salinity level (see Table 1, in III c), driven by the human driven river damming process. Since most grass species of these land areas are intolerant to that high salinity, these lands have lost their grass cover – the biodiversity underpinning the soil erosion regulation service flow, and they become exposed to soil erosion. Thus, two drivers of ecosystem change – human induced soil salinity followed by soil erosion – jointly underly an instance of 'land degradation' in Banni. However, *Pj* is resilient to these areas' extreme salinity, so that its cover, even if sparse (see Table 1), would underpin the soil erosion regulation service flow. Thus, once processes of salinity mitigation would become operational, with *Pj* cover functioning as a mitigator of soil erosion, the economic productivity of the land would be restored; this exemplifies a case of *Pj* functioning as a driver of full land restoration in some areas of Banni grassland.

In addition, *Pj* also underpins the global climate change regulation service through the process of carbon sequestration, wherever it covers Banni. Here again its above- and below-ground live and dead biomass, of dimensions that enable engaging and benefiting from the carbon trade, is an as of yet unrealized benefit. Note that for the benefits presented in the Benefits Box that would support human well-being, mainly the Banni economy component, the anthropogenic assets (listed in this box, and more) need

to be used (arrow 5 and then 6). Additional regulating services underpinned by *Pj* (not presented in Fig. 11c) are water flow and purification regulation (Walter & Armstrong, 2014). Finally, the current and future state of Banni's socio-ecological system as presented in Fig. 11c, lies in the hands of the Human system to control its underlying drivers of change (arrow 7), such that the grassland's ecosystem state and its services, as presented in Fig. 11c, will continue to sustain an acceptable level of the Banni people's well-being.

Furthermore, while Figures 11a, b, and c show the dynamics within the network of inter-linkages of the variables and processes of Banni's socio-ecosystem, moving from sustainability, to degradation, and then restoration, Table 3 adds a final dimension to the story; that is, the chronology of events that shaped the trends of processes in the Banni socio-ecosystem (i.e., whether they increased, decreased, or remained stable), and their vicissitudes over six decades, from 1960 to 2015.

Table 3: Chronology of Banni processes' vicissitudes, 1960 – 2015



The table, based on our review data, presents the trends of ten Banni variables and the processes and drivers underlying these changes. One variable (milk sale), emerged only in the 3rd decade, and two others (*Pj* biomass and charcoal sale) in the 4th decade; in both cases, their growth stabilized after the first decade of their appearance. Soil salinity is the sole variable that remained stable throughout the early 1960s, and then it continually increased throughout the entire review period. Altogether, the trends of these four variables changed twice.

Trends of the interlinked grass cover and forage provision changed 4 times, bullock sales 5 times, and the remaining variables, 3 times each. Finally, in the last review decade (the 2010s), seven of the ten variables remained stable, and three – the ecosystem services' benefits, *i.e.,* sales of milk, charcoal and bullocks, continue contributing to the resilience of Banni's human well-being, even though grass cover has not yet been fully stabilized.

Given all this, it is likely that Land Degradation Neutrality (LDN), i.e., *"an ecosystem's state whose functions and services that promote food security, remain stable"* (UNCCD, 2015), is achievable, in Banni and in other sites experiencing similar circumstances.

VII. Conclusions and Recommendatins

Our review describes a rolling course of socio-ecological crisis management of a reputable rangeland in Asia, the Banni Grassland in India, which was threatened with land degradation by soil salinization resulting in reduced biological productivity on which this ecosystem users' livelihoods depend. The salinization

process was generated by two distinct, but mutually independent drivers, of which authorities were aware. Nevertheless, from the beginning, management focused only on the first driver (windborne salt particles from an adjacent saline desert). This approach not only failed to moderate the strength of the driver, but it heightened the threat to the biodiversity component (livestock's edible grass plants), and thus to the grassland people's livelihood and lifestyle. Meantime, management ignored the more active driver - stoppage of the annual freshwater flow by damming the rivers that open into Banni and leach the soil surface salt deposited through capillary movement of Banni saline groundwater.

The outcome of the actions taken in response to the crisis led us to two conclusions/ recommendations: first, do not look for solutions until you have identified and fully recognized the drivers of the crisis; and second, do not use a biodiversity component as a remedy until you have fully studied and understood its natural history and its function and behavior in its habitats and ecosystems. These two conclusions/recommendations are not new and may even seem trivial, but our 60-year review of the Banni grassland ecosystem adds to their support and strength, as based on crisis management of a single grassland ecosystem, for which the chosen remedy was an alien plant, one that is also a notoriously invasive species.

Moreover, Banni's case shows that effective management of an ecosystem requires not only literacy of the used ecosystem and of the species that are candidates for responding to drivers of its degradation, but also an understanding of its human system: both the people living in the ecosystem and using its services, their culture, needs and aspirations; and the authorities – local and external – who have influence and power in matters concerning the ecosystem, its users and their well-being. These are reflected in the third conclusion/recommendation: an effective response to ecosystem degradation requires familiarity with and knowledge of, the ecosystem-human system interactions.

These recommendations are based on knowledge gained from 60 years of trial-and-error wrestling with an invasive alien, widely known to be harmful as an 'ecosystem engineer unleashed' (Ayanu *et al.*, 2015), which managed to reduce the flow of the major provisioning service of the invaded ecosystem. The lessons learned enabled conversion of the invasive alien to a biodiversity component underpinning a novel ecosystem service, thus offsetting the partial loss of the grass provisioning service, and fully restoring the land's biological productivity of economic value, while maintaining the traditional indigenous livelihood, diversifying the ecosystem service bundle, and increasing the users' livelihood resilience.

Thus, our review presents a case of tackling land degradation based on retaining critical levels of natural capital; *i.e.,* lands of tolerable salinity and their grass cover, while basing the ecosystem users' livelihoods on a wider range of ecosystem services. Our review, therefore, supports a vision of sustainable coexistence of grass and *Pj* in a spatial land mosaic, and diversity of sustainable livelihoods in the Banni grassland. This is in contradiction to science-based recommendations for Banni proposing that "…. *land under P. juliflora needs to be cleared"* and "… *Prosopis removal policy … is a favorable policy option*" for Banni (Mathur & Sharma, 2018). Another science-based study, however, proposes to "… *strengthen the positive aspects of Prosopis, a naturalized resource that has come to India to stay*" (Walter & Armstrong, 2014). Our advice to the bewildered, therefore, is to attend available experiences yet not give up until you've explored other "out of the box" approaches.

Regarding this advice and noting that Banni case of restoration/rehabilitation of an Indian desert grassland ecosystem degraded by an alien species invasion is not unique; further search may reveal similar but not identical cases. Here we present one case of "out of the box" solution, the rehabilitation of an Inner Mongolian grassland ecosystem, Hunshandake Sandland (HS) (King C., 2008). In this case the degradation is caused not by an invasive alien species, but by overgrazing. In both Banni and HS the direct consumers of the grass cover are livestock, mostly cattle, but the loss of forage in Banni was caused by the alien *Pj* outcompeting the forage plants, while in HS, overgrazing has limited the ability of the land to carry enough animals to sustain the livelihoods of local families.

In neither case has the pre-degradation stage been restored; neither Banni's total land's grass cover, nor HS's grass productivity per land unit. Rather, in both cases the ecosystem has been rehabilitated by human-driven introductions; of an invasive alien plant species in Banni, and of a less destructive livestock species (chicken) in HS. Both Banni and HS benefited from the new species, which yielded diversified income sources for livelihoods; the sale of charcoal in Banni and of chicken eggs in HS. Thus, in both cases, the ecosystems' rehabilitation fully restored and even increased the income from the ecosystems, *i.e.,* the ecosystem-based human well-being of the locals. And, in both cases the deep-rooted attachment of the local herders to the pastoral tradition – *i.e.*, a benefit of the ecosystems' cultural service – has been maintained, such that altogether, full restoration of human well-being achieved in both cases, maybe both through 'out of the box' solutions.

Returning to the Banni case, we suggest that the Conceptual Framework of Banni Grassland Socio-

Ecosystem – the Banni-adapted conceptual framework of biodiversity and ecosystem services (Figs.11a, b, and c), can function as an algorithm for moving from natural capital (the ecosystem's biodiversity) to human well-being, and from degraded land towards its sustainable management. This, together with our two algorithms (see V b) "Calculating Banni charcoal-based livelihood's income from sustainably harvesting *Pj* land cover biomass", and "Projecting Banni population size sustainably supported by Banni *Pj* land cover", can function as effective guidelines for implementing a successful transition from non-sustainable to sustainable ecosystem use. For example, in the case of Banni, use of these guidelines saw *Pj* transformed from an agent of land degradation to an agent of land restoration, as a result of residents' and authorities' informed joint intervention.

Furthermore, these guidelines may be useful not only at the local level, but also at regional and global levels, such as contributing to the global intergovernmental effort for achieving, by 2030, the United Nations Sustainable Development Goals – and specifically its 15.3 target. These call for *"restoring degraded land and soil"* and striving to "*achieve a land degradation-neutral world*", when success would be based on comparing the state of functions and human well-being of a focal socio-ecosystem in 2030 to those prevailing in 2015, the last year of our Banni review.

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Assessment of Public Participation as Mechanism for Sustainable Waste Management in Barnawa, Kaduna South, Kaduna State, Nigeria

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Abstract- The study was an assessment of public participation as a mechanism for sustainable waste management in Barnawa, Kaduna South, Kaduna state. The study was descriptive cross-sectional survey that employed the use of both primary and secondary data obtained from field survey, journal, articles, and text books. The sampled size of the participants of the study was 100 residents in the study area, while the statistical method of analysis adopted in analysing the results obtained was descriptive statistics. The results revealed that the most common waste generated are; residential waste, paper waste, plastic waste, textile waste, bottle waste and commercial waste. More so, the results revealed that these wastes as well as solid waste were generated on a frequency of daily basis, weekly basis and twice a week basis in the study area. The result collected from the field survey to this respect revealed that there are basically three stakeholders responsible. More so it was reviled the cost of solid waste disposal in the study area, as well as the willingness of the residents of Barnawa community to pay for disposal of solid waste in the community.

Keywords: *waste, public, participation, sustainable, management.*

GJSFR-H Classification: *FOR Code: 900401*

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Keywords: waste, public, participation, sustainable, management.

I. Introduction

Waste is any unwanted and discarded object or material, which could be in the form of plastics, rubber, metals (liquid, gaseous and solid forms), oil and other inorganic and organic matter, which is a by-product from industrial, institutional, agricultural or household activities (Benedine *et al.,* 2011, Bogoro & Babanyara, 2011). Waste is something for which we have no further use and which we wish to get rid of. Solid wastes arise from unusable residues in raw materials, leftovers, rejects and scrap from process operations, used or scrap packaging materials and even the saleable products themselves when they are finally discarded. The management of municipal solid waste has been a persistent challenge to the government of most cities in developing countries, Nigeria inclusive and a considerable amount of money goes into the management of such huge volumes of solid waste. Consequently, vast uncollected waste results in different social menaces e.g., it causes diseases, clogs drains causing flooding and also environmental. Pollution in developing countries it is estimated that one to two thirds of the solid waste generated in most urban areas is not collected (Zurbrugg, 2003).

Medina, (2000) defined solid waste as materials generated from the result of human daily activities resulting from areas such as households, public places and city streets, shops, offices and hospitals. Solid waste management can be defined as a discipline associated with control of generation, storage, collection, transfer, processing and disposal of municipal solid waste in a way governed by the best principles of public health, economics, engineering, aesthetics and other environmental considerations. Public participation as concept is defined by Phago and Hanyane (2007) as a constitutional mandate that involves exchange in information between the public at the grass roots level and the legitimate government structures. The authors believe that communities are stakeholders in the government sphere and should therefore be encouraged to participate in matters of local government to sustain waste management service delivery.

Smith and Vawda (2003) point out that public participation is a key strategy for building democracy. The authors maintain that the scope of public participation should be widened to determine distribution and allocation of resources to improve the quality of lives of the poor. The authors advocate that by

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capacitating people to participate in public issues, the public will be developed to engage in the community matters. According to Tsenoli (2010) it is of vital importance to improve and encourage public participation, especially in government policy formulation and implementation. The role of Kaduna South Metropolis should be to raise awareness of the rights and obligations so that the public is able to play an active role in municipal affairs.

Public participation is a process that cannot be ignored. Kroukamp (2000) states that if the public is offered an opportunity to participate in a community's services such as waste management, they become responsible, find meaning in what they do and the municipality is able to mobilize financial and material resources to service the community better. Khoso (2000) maintains that public participation is a prerequisite in waste management infrastructure such as mini-recycling facilities, buy back centres and mini dump transfer stations. A community that involves the public develops partnership with stakeholders and acknowledges that public participation is a cornerstone of a democratic country that benefits politicians, officials and the public itself. The needs of the public become known through their involvement (Kroukamp, 2000). The Waste Act defines waste management as "any activity listed in Schedule 1 or published by notice in Gazette under Section 19 and includes the importation and exportation of waste, the generation of waste including the undertaking of any activity or process that is likely to result in the generation of waste". According to Scheinberg (2008) the process and activity in waste management "give priority to waste prevention and recovery, shifting the destination of materials away from land disposal to formal and informal re-use, recycling and composting". The unwanted waste is managed separately; transported, transferred and disposed at the disposal site.

Kaduna metropolis like most major urban centres in Nigeria is experiencing rapid increase in urban population due to mainly rural - urban migration. The increase in solid waste generation has been found to be the direct result of increase in population growth which as well applies to Barnawa community being one of the major communities in Kaduna South. The management of solid waste in the city of Kaduna is largely carried out by the Kaduna Environmental Protection Agency (KEPA) Result from previous studies and observation as indicated by the heaps of uncollected waste seen across the streets of the metropolis shows that government agencies do not have the capability to consistently rid the city of waste as often as they are being generated. This is further compounded by the high cost of managing waste amidst the growing demand for funds by other sectors of the economy with only limited resources available both in terms of man power and financial cost. The result of this is the relatively high and substantial quantity of the generated waste is being left uncollected. As a result of this challenge, public participation in solid waste management has become inevitable.

Preliminary observation and studies have shown that with a well-organized and planned structure in place, communities can effectively manage their solid waste. This preliminary observation revealed that there already exist certain practices by the households towards managing their waste. Barnawa has diverse communities with varying needs. Their social characteristics range from affluent to poor socio-economic status. Poor service quality of refuse collection affects the quality of lives of the people in these communities. Poor refuse collection services limit business and industries in an area and deprive the community of job opportunities. If people are consulted about service levels, problems and proposals for new services, irrespective of their socio-economic status, they will see no need to protest about poor service delivery because they have been informed and may contribute to solution of problems.

Some factors contributing to slow public participation in waste management in Barnawa communities are:

- There seems to be much public ignorance on the relationship between active public participation in waste management and healthy environment due to lack of involvement of community in waste management in Kaduna South metropolis.
- Other weaknesses affecting public participation in waste management services are increase in population leading to excessive waste generation in the region.
- People are informed but are not interested. Some people work far from their homes and play a very little role in public meetings as they arrive home late.
- Inadequate consensus whereby people with sufficient knowledge and have ability to debate issues may not be present in the public participation meeting. The inverse may occur where there are professionals who are able to interpret the policy that is under discussion. This may need a follow-up to the meeting.
- Inflexible project design to promote participation. This may need a series of public meetings and categorize residents into business, community and education sector.

The focus of this study is to determine the extent of community involvement in waste management processes in Kaduna South. That way, the gaps in public policy implementation in waste management would be highlighted for management action.

II. Materials and Methods

a) Nature and Sources of Data

The study employed the use of both primary and secondary data. Primary data used was a cross sectional survey data from residents of the study area. The natures of the secondary data of the study were existing qualitative data that were relative to the study. The Secondary were sourced from journals, articles, and books.

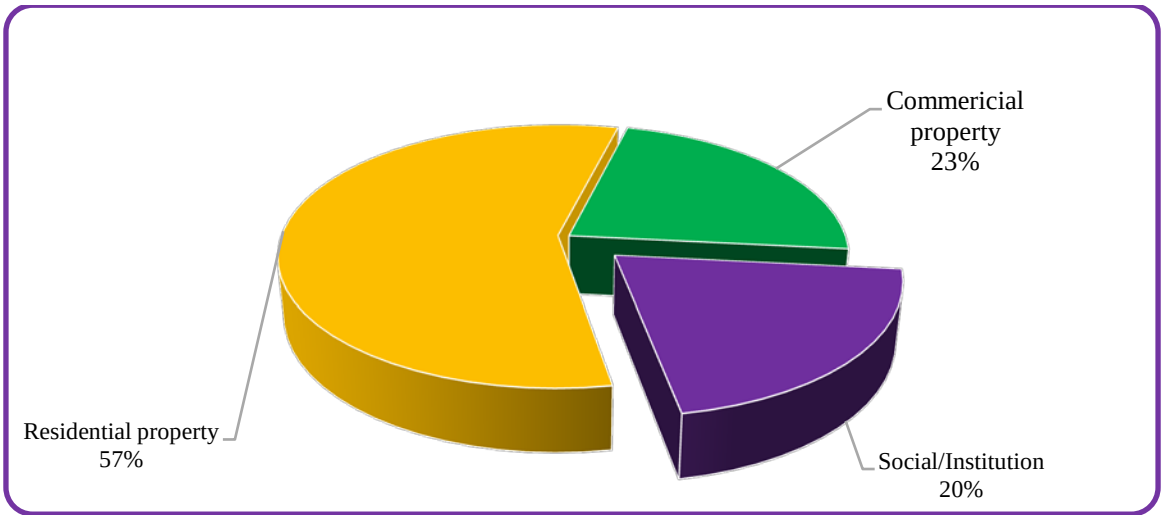
b) Method of Data Analysis

The data for this study was processed and analysed both quantitatively and qualitatively. The quantitative data was analysed using both descriptive statistics with the help of Microsoft Excel, and IBM SPSS Statistical package version 26. The descriptive statistics that was used consist of central tendency and simple percentages. The results obtained from the field survey were presented in the form of charts and tables.

III. Results and Discussion

a) Nature of Property Respondents of the Study

The results depicted in Figure 1 reveals the distribution of the nature of the property of the respondents of the study. From the chart, it can be observed that majority of the nature of property of the participants of the study were residential property. This group of respondents accounted for 57 percent of the respondents of the study. More so, 23 percent of the respondents of the study highlighted that the nature of the property the possessed/occupy are commercial property, while 20 percent of the respondents of the study were of the opinion the nature of the property they occupy/possessed in the course of this study were social/institutional property.

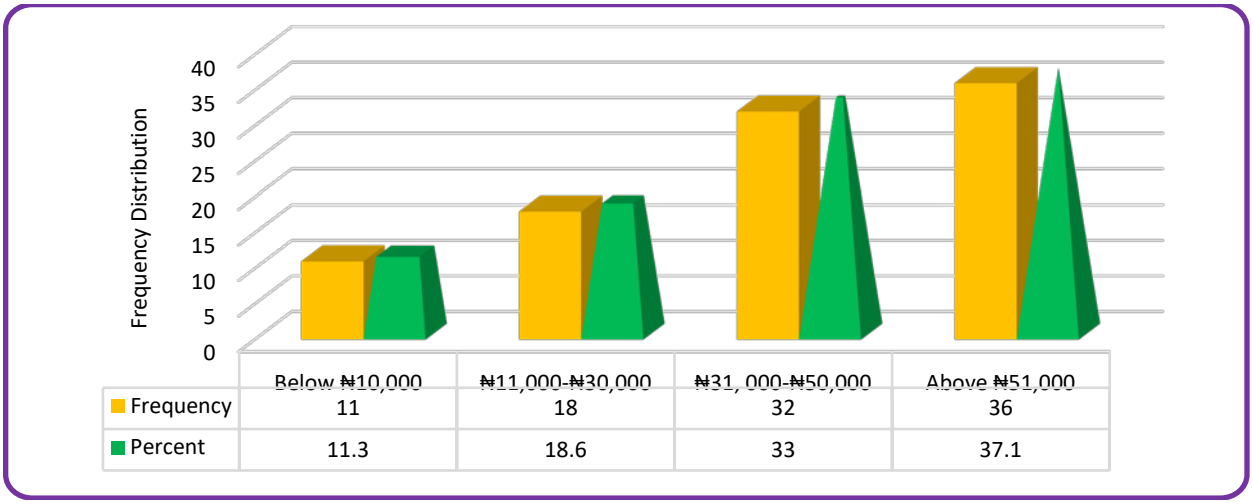


Source: author's computation, 2020.

Fig. 1: Nature of Property of Respondents

b) Income level per month of Respondents of the Study

The results of the study also reveal the income level per month of the respondents of the study, as depicted in Figure 2. The findings revealed that 37.1 percent (36 respondents) respondents of the study earn an average income level of above ₦51,000 per month in the study area. Similarly, the depicted results revealed that 33 percent (32 respondents) of the respondents of the study earn an average income level between ₦31,000-₦50,000. More so, the result further revealed that respondents of the study earning an average income level between ₦11,000-₦30,000 accounted for 18.6 percent (18 respondents) respondents of the study, while respondents earning an average income level below ₦10,000 per month accounted for 11.3 percent (11 respondents) respondents of the study.



Source: author's computation, 2020.

Fig. 2: Income per month of Respondents

c) Types Waste Generated in the Study Area

The study attempts to establish the types of waste generated by the residents of Barnawa community in the study area. The results of the various responses of the respondents of the study with respect to the various types of waste generated are presented in Table1. From the results, it can be discovered that there are basically six major waste generated by the residents of Barnawa community. These wastes include; residential waste, paper waste, plastic waste, textile waste, bottle waste, and commercial waste. It is however important to note that among these six major types waste generated in the study area, residential and plastic waste are the highest waste generated by residents in the community.

Table 4.1: Types of Waste Generated in the Study Area

I mostly generate residential waste			I mostly generate paper waste		
Reponses	Frequency	Percent	Reponses	Frequency	Percent
Strongly Disagree	10	10.3	Strongly Disagree	25	25.8
Disagree	18	18.6	Disagree	16	16.5
Undecided	17	17.5	Undecided	12	12.4
Strongly agree	34	35.1	Strongly agree	26	26.8
Agree	18	18.6	Agree	18	18.6
Total	97	100.0	Total	97	100.0
I mostly generate metal waste			I mostly generate organic waste		
Strongly Disagree	28	28.9	Strongly Disagree	32	33.0
Disagree	24	24.7	Disagree	25	25.8
Undecided	18	18.6	Undecided	15	15.5
Strongly agree	17	17.5	Strongly agree	17	17.5
Agree	10	10.3	Agree	8	8.2
Total	97	100.0	Total	97	100.0
I mostly generate plastic waste			I mostly generate textile waste		
Strongly Disagree	13	13.4	Strongly Disagree	24	24.7
Disagree	17	17.5	Disagree	18	18.6
Undecided	17	17.5	Undecided	11	11.3
Strongly agree	30	30.9	Strongly agree	24	24.7
Agree	20	20.6	Agree	20	20.6
Total	97	100.0	Total	97	100.0
I mostly generate bottle waste			I mostly generate commercial waste		
Strongly Disagree	19	19.6	Strongly Disagree	17	17.5
Disagree	16	16.5	Disagree	21	21.6
Undecided	17	17.5	Undecided	15	15.5
Strongly agree	19	19.6	Strongly agree	21	21.6
Agree	26	26.8	Agree	23	23.7
Total	97	100.0	Total	97	100.0

I mostly generate industrial waste			Most Generated Waste in the Study Area Based on Responses of the Respondents
Strongly Disagree	21	21.6	Residential Waste
Disagree	24	24.7	Paper Waste
Undecided	16	16.5	Plastic Waste
Strongly agree	18	18.6	Textile Waste
Agree	18	18.6	Bottle Waste
Total	97	100.0	Commercial Waste

Source: field survey, 2020.

d) *Frequency of Solid Waste Generation and Disposal in the Study Are*

The study sought to assess the frequency of solid waste generation by residents in the study area, as well as the frequency of disposal of these solid wastes. The result presented in Table 2 reveals the frequency of solid waste generated in Barnawa community.

Table 2: Frequency of Solid Waste Generation in the Study Area

Period	Frequency	Percent	Valid Percent	Cumulative Percent
Daily	38	38.0	39.2	39.2
Twice a week	31	31.0	32.0	71.1
Weekly	28	28.0	28.9	100.0
Total	97	97.0	100.0	

Source: filed survey, 2020.

From the frequency distribution of the responses of the respondents of the study, it can be observed that an average level, solid waste in the study area is generated on a daily basis. The conclusion was arrived at with respect to 38 percent majority responses from the respondents of the study, who were of the opinion that they generate solid waste in the study area on a daily basis.

Table 3: Frequency of Solid Waste Disposal in the Study Area

Period	Frequency	Percent	Valid Percent	Cumulative Percent
Daily	26	26.0	26.8	26.8
Twice a week	35	35.0	36.1	62.9
Weekly	36	36.0	37.1	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

In an attempt to establish the frequency to which residents of the study area dispose the solid waste they generate, the results presented in Table 3 revealed that the majority of residents in the study area dispose the solid waste the generate on a weekly or twice a week.

e) *Stakeholders Responsible for Solid Waste Management in the Study Are*

The study attempts to identify the various stakeholders involved in solid waste management in Barnawa community. The results presented in Table 4 reveal the finding made with respect to this objective of the study. From the frequency distribution of the various responses of the respondents of the study, it can be observed that that major stakeholders involved in solid waste management in the area of study are; government waste management agency, private waste management companies, and community based voluntary waste management group.

Table 4: Stakeholders Involved in Solid Waste Management in Study Area

Stakeholders	Frequency	Percent	Valid Percent	Cumulative Percent
Government waste management agency	36	36.0	37.1	37.1
Private waste management companies	31	31.0	32.0	69.1
Community based voluntary waste management group	30	30.0	30.9	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

Having identified the various stakeholders involved in solid waste management in the area of study, the study sought to highlight the effectiveness of these stakeholders in the management of solid waste in the study area. To this end, the participants of the study were asked whether these stakeholders were effective in managing sold waste in Barnawa community via one of the items on the research instrument. The data presented in Table 5 depicts the various responses of the participants of the study, vis-à-vis the perceived effectiveness of these stakeholders.

Table 5: Effectiveness of Stakeholders in Solid Waste Management in the Study Area

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	33	33.0	34.0	34.0
No	44	44.0	45.4	79.4
No idea	20	20.0	20.6	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

From the above results depicted in Table 5, it can be observed that majority of the respondents of the study (45.6 percent) were of the view that the stakeholders involved in solid waste management were not effective.

Having established the effectiveness of stakeholders in solid waste management in the study area, the study sought to identify the various means by which waste are collected by the various institutions involved in waste management in the study area. The results presented in Table 6 reveals these means, as indicated by the degree of responses of the participants of the study.

Table 6: Means of Waste Collection in the Study Area

Means	Frequency	Percent	Valid Percent	Cumulative Percent
Trucks	14	14.0	14.4	14.4
Wheel barrow	51	51.0	52.6	67.0
Other	32	32.0	33.0	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

From the above results presented in Table 6, it can be observed that most common mean of waste collection in the study area was by wheel barrow. Although trucks are used for waste collection, there usages however, are not popular. The respondents of the study however did point out that other mean of waste collection not highlighted in the research instrument were used for waste collection in Barnawa community.

Table 7: Frequency of Waste Collected by Stakeholders Involved in Waste Management in the Study Area

Frequency of Collection	Frequency	Percent	Valid Percent	Cumulative Percent
Daily	11	11.0	11.3	45.4
Twice a week	16	16.0	16.5	61.9
Weekly	26	26.0	26.8	88.7
Monthly	44	44.0	45.4	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

The result presented in Table 7 reveals the frequency of waste collection by the various stakeholders in waste management in the study area. From the above results, it can be observed that the majority of the respondents of the study were of the opinion that waste was collected monthly. This group of respondents accounted for 45.4 percent of the respondents of the study. Although other respondents of the study pointed out different frequency of waste collection by stakeholder of waste management in the study area, it is prudent to conclude that these frequencies of waste collection are carried out independently by different stakeholders. However, the majority of waste collection in the study area is usually done on a monthly basis.

Table 8: Method of Waste Disposal by Stakeholders Involved in Waste Management in the Study Area

Method	Frequency	Percent	Valid Percent	Cumulative Percent
Incineration	61	61.0	62.9	62.9
Burying	36	36.0	37.1	100.0
Total	97	97.0	100.0	

Source, field survey, 2020.

The study attempts to establish the most common method of waste disposal employed by the various stakeholders involved in waste management in the study area. The results presented in Table 8 highlight the responses of the respondents of the study. From the frequency distribution of their responses, it can be concluded that the most common method of waste disposal employed in waste management in the study area was by incineration.

f) Cost of Solid Waste Disposal and Willingness to Pay for Disposal of Solid Waste

One of the objectives of the study was to assess the willingness of the residents of the study area to pay the solid waste management, vis-à-vis its cost affordability. To this respect, respondents in the study area were asked whether waste management institutions charge fees for disposing solid waste in the study area, their perception on the affordability of these fees, and the willingness of households in the study area to pay for solid waste management services.

Table 9: Do Waste Management Institutions Charge Fees for Disposing Waste in Barnawa community?

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	63	63.0	64.9	64.9
No	34	34.0	35.1	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

The results presented in Table 9 shows that majority of majority of the institutions responsible for solid waste management in Barnawa community charge service fees for disposing solid waste in the study area. Although some of the response of the respondents of the study suggest that waste management institutions do not charge services fee for waste disposal, the study concluded that some of the waste management institution in Barnawa community do not charge services fees for solid waste management.

Table 10: Affordability of Charges Fees Affordable for the Average Household in Barnawa Community

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	32	32.0	33.0	33.0
No	40	40.0	41.2	74.2
No idea	25	25.0	25.8	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

The results presented in Table 10 represents the responses of the respondents of the study as to whether these charges fees charged by waste management institutions in the study area are affordable. From the frequency distribution of the responses of the participants of the study, the study concluded that the service fees charges by these institutions are not affordable for the average household in the study, as indicated by 41.2 percent majority response.

Table 11: Willingness of Households in the Study Area to Pay for Solid Waste Management Services

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
Always	26	26.0	26.8	26.8
Sometimes	36	36.0	37.1	63.9
No	35	35.0	36.1	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

With respect to the willingness of the residents in the study area to pay for solid waste management services in the study area, the result presented in Table 11 represents the opinions of the participants of the study with respect to the subject. From the results, it can be observed that 37.1 percent of the respondents of the study were of the notion that households in the study area are sometimes willing to pay for solid waste management services provided in the study area, while 36.1 percent of the respondents were of the response that households in the study area are not willing to pay for this service. More so, the result reveals that 26.8 percent of the respondents were of the opinion that households are always willing to pay from these services. Hence, from these results the study concluded that households in the study area are not willing to pay for solid waste management service in Barnawa community, and when they eventually do, they only do so on occasional cases.

Table 12: Ways of Waste Disposal Employed by Residents of the Study Area

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
I employ the services of waste management institutions in my community	29	29.0	29.9	29.9
I incinerate the waste i generate	24	24.0	24.7	54.6
I bury the waste i generate	24	24.0	24.7	79.4
I dump the waste i generate in open dumpsites	20	20.0	20.6	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

The study further attempts to assess the various ways residents in the study area employ in disposing the waste they generate. The data presented in Table 12 represents the various ways employed by the residents of Barnawa community is disposing the waste they generate. From the frequency distribution of the responses of the respondents, it can be observed that majority of the residents in the study area employ the services of waste management institutions in the community. The results of the study also revealed that some residents of the study area incinerate the waste they generate. More so, the result revealed that some residents in the study area bury the waste they generate, as a way of disposing such waste. The results also revealed that dumping of waste in open dumpsites is one of the ways used residents in the study area indisposing the waste they generate.

The study attempts to assess whether the residents of the study area usually encounter challenges in disposing their waste. From the results presented in Table 13, it can be observed that 49.5 percent of the respondents of the study were of the opinion that they encounter challenges in disposing waste, while 50.5 percent of the respondents were of the opinion that they do not encounter and challenges whatsoever in disposing their waste in the study area.

Table 13: Do You Encounter any Challenge in Disposing the Waste you generate?

Responses	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	48	48.0	49.5	49.5
No	49	49.0	50.5	100.0
Total	97	97.0	100.0	

Source: field survey, 2020.

Given the results presented in Table 13, the attempts were made to identify the possible challenges residents in the study area encountered in disposing waste. The results presented Table 4.14 reveals the challenges pointed out the respondents the study. From the results it can be observed the major challenges residents of the study area encounter as indicated by the frequency of responses are; proximity to dumpsites, and lack of modern waste management facilities. Other challenges included; cost of waste management charges fees, shortage of personnel of waste management institutions and others not captured in the research instruments.

Table 14: Challenge Encountered in the Course of Disposing Waste in the Study Area

Responses	Frequency	Percent	Valid Percei	Cumulative Percent
Cost of waste management charges fee	19	19.0	19.6	19.6
Proximity to waste dumpsites	29	29.0	29.9	49.5
Lack of modern waste management facilities	24	24.0	24.7	74.2
Shortage of personnel of waste management institutions	16	16.0	16.5	90.7
Others	9	9.0	9.3	100.0
Total	97	97.0	100.0	

Source: field survey, 2020

IV. Conclusion

Long-term sustainability of the solid waste management system also depends on the level of segregation of waste. Segregation of waste should be three streamsi.e., bio-degradable, recyclables and garbage/waste; this will also help in finding appropriate disposal options. Segregation of waste should be done at the source itself. Segregated waste can be collected on a weekly basis from households and on a daily basis from business establishments.

Collection of the waste should be undertaken at the doorstep level and people from economically backward sections may be employed for the same. These people should be properly trained and equipped. The collected non-degradable materials should be removed using covered trucks and trailers. Care should be taken not to spill the waste during transportation. All the collection workers should be provided with proper handling equipment and their safety should be ensured by Barnawa community.

Disposal of the waste should be undertaken in a prescribed scientific manner. A sanitary landfill designed specifically for the final disposal of wastes should be built. Sanitary landfills minimize the risks to human health and the environment associated with solid wastes. Formal engineering preparations with an examination of geological and hydrological features and related environmental impact analysis should be carried out before a sanitary landfill is built. Staff working in the sanitary landfill should be properly equipped and trained. Darjeeling municipality should find a proper location for a sanitary landfill. Disposal of hazardous waste such as medical or toxic waste should be undertaken with the help of the state government. Special provisions should be made to adequately deal with these wastes, and special transportation facilities and specially trained staff should be employed for dealing with hazardous wastes. The municipality should immediately seek help from the State and the Central government in this regard.

Emphasis should be placed on the three R's – reduction, reuse, and recycle. This will help in creating of less waste and in increased material recovery. Reduction can be achieved by starting a deposit-refund system, i.e., it should be made compulsory for certain types of waste to be taken care of by the company producing them under extended producer's responsibilities. In order to ensure that these particular wastes go back to the producers, an extra deposit could be charged when someone purchases these items, and this deposit should be recoverable on return of the items (say cover/foil/plastic bottles etc.). This may reduce the burden of waste to a great extent. Wastes such as chip packages, drinking water bottles, soft-drink bottles, etc. should be included in this system. The recycling of waste is another important requirement for sustainable waste management practices. In the case of the Barnawa community, a formalized waste recycling or recovery system, should be undertaken. NGOs or private firms may be enlisted in organizing and including the non-formal recycling sector as part of the formal system. Rag pickers or itinerant buyers should be allocated in such a manner that the maximum amount of waste is recovered for recycling.

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Analysis of Land-Use Conflict between Farmers and Pastoralists in Gwagwalada Area Council of Abuja, Nigeria

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Abstract- The issue of land-use conflict between farmers and pastoralists of recent had become an alarming situation which requires urgent attention due to its nature and effects in term of socio-economic imbalance, poor welfare, political indifference, cultural and ethnic belief. This study analyses Land-use Conflict between Farmers and Pastoralist in Gwagwalada Area Council, Abuja, Nigeria. Data were source using a structured questionnaire. 400 questionnaire were administered to 10 selected wards in Gwagwalada Area Council. Purposive and multi-stage techniques were used for this study. 322 questionnaires were administered to the farmers while 78 were for the pastoralist. Descriptive statistics such as; mean, standard deviation, and Wilcox on Sum Rank Test (WSRT) analysis were employed in the analysis. The study reveals that blockage and reduction of the size of the stock route and access to water points are the major causes of conflict between the farmers and pastoralists. On the effect of the of land-use conflict; farmers identify destruction of crops (mean=3.6), follow by mean=2.8 on the displacement of farmers/Fulanis, and mean= 2.4 on Loss of house, while pastoralist's Major effects of the conflict were; mean=5.1 on the loss of lives/cattle, follow by mean=4.8 on Loss of houses and properties amongst others.

Keywords: land, conflict, farmers, herdsmen, and community.

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Analysis of Land-Use Conflict between Farmers and Pastoralists in Gwagwalada Area Council of Abuja, Nigeria

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Abstract- The issue of land-use conflict between farmers and pastoralists of recent had become an alarming situation which requires urgent attention due to its nature and effects in term of socio-economic imbalance, poor welfare, political indifference, cultural and ethnic belief. This study analyses Land-use Conflict between Farmers and Pastoralist in Gwagwalada Area Council, Abuja, Nigeria. Data were source using a structured questionnaire. 400 questionnaire were administered to 10 selected wards in Gwagwalada Area Council. Purposive and multi-stage techniques were used for this study. 322 questionnaires were administered to the farmers while 78 were for the pastoralist. Descriptive statistics such as; mean, standard deviation, and Wilcox on Sum Rank Test (WSRT) analysis were employed in the analysis. The study reveals that blockage and reduction of the size of the stock route and access to water points are the major causes of conflict between the farmers and pastoralists. On the effect of the of land-use conflict; farmers identify destruction of crops (mean=3.6), follow by mean=2.8 on the displacement of farmers/Fulanis, and mean= 2.4 on Loss of house, while pastoralist's Major effects of the conflict were; mean=5.1 on the loss of lives/cattle, follow by mean=4.8 on Loss of houses and properties amongst others. Therefore, the study recommends that sensitization of stakeholders – farmers and herdsmen on the mutual co-existence of peace should be advocated, this would help to forestall needless provocations and opportunistic violence between farmers and herdsmen. Also, Government should amend the land use Act and come up with new policies to benefit both the farmers and pastoralists.

Keywords: land, conflict, farmers, herdsmen, and community.

I. Introduction

Land-use Conflict is not infrequent and perhaps not abnormal in human natural balance. Increasing demand for natural resources caused by increasing human population, climate variability, development projects, and other land-use activities thus lead to pressure on arable land Okoli (2014). Land conflicts are indeed a widespread phenomenon and can occur at any time or place. Both need and greed can equally lead to them, scarcity and increases in land value can make things worse (Olanrewaju, 2013). The growth in the magnitude of herds and the production of livestock in the arid and semi-arid regions constrained by inconsistency in the period of rainfall are some of the factors responsible for the prevalence of the conflict between farmers and herdsmen in West Africa wherein Nigeria is situated (Abbass, 2012). However, this necessitates the call for the herdsmen to move around the regions in search of pasture for animals and sustainable management of the rangelands (Shettima and Tar, 2008).

There is a long historical record of fluctuating conflict, competition, and cooperation between settled farmers and pastoral or transhumant herders. This includes periods of violent herder domination over settled farming production systems and the conversion of former pastoral lands to cultivation. The current levels of conflict that occur in some locations are intolerable for farmers, herders, and also for the environment. The need for local communities to resort to such violence is indicative of a lack of policies, or that existing policies are not working to the benefit of these communities as a whole.

Moore (2005) noted that conflict per se, is not bad: it is perhaps a necessity in the evolution and development of human organizations. But when conflict degenerates to violent, destructive clashes, they become not only unhealthy but also counterproductive and progress-threatening. Therefore, the conflict between the farmers and herders has remained one of the most outweighing resource-use conflicts in Nigeria (Wulster-Radcliffe. et al., 2004; Fasona and Omojola, 2005). The expansion of Fulbe pastoralism into Nigeria is unknown. It is suggested that Fulbe began to settle on the plains of Bauchi Emirate transcending onto the grassland of the Jos Plateau (Morrison, 1982). Conflicts between pastoralists and farmers have existed since the beginnings of agriculture and increased or decreased in intensity and frequency depending on economic, environmental, and other factors. For example, increases in the herd sizes, due to improved conditions of the cattle, compelled the pastoralists to seek more pastures beyond their limited range. Climate change has constituted a great threat by putting great pressures on the land and thus provoking conflicts between them.

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However, improvements in human health and population have enhanced a much greater pressure on land.

Some studies evidenced on the pervasiveness of conflict in north-central Nigeria includes; Modupe, 1996;

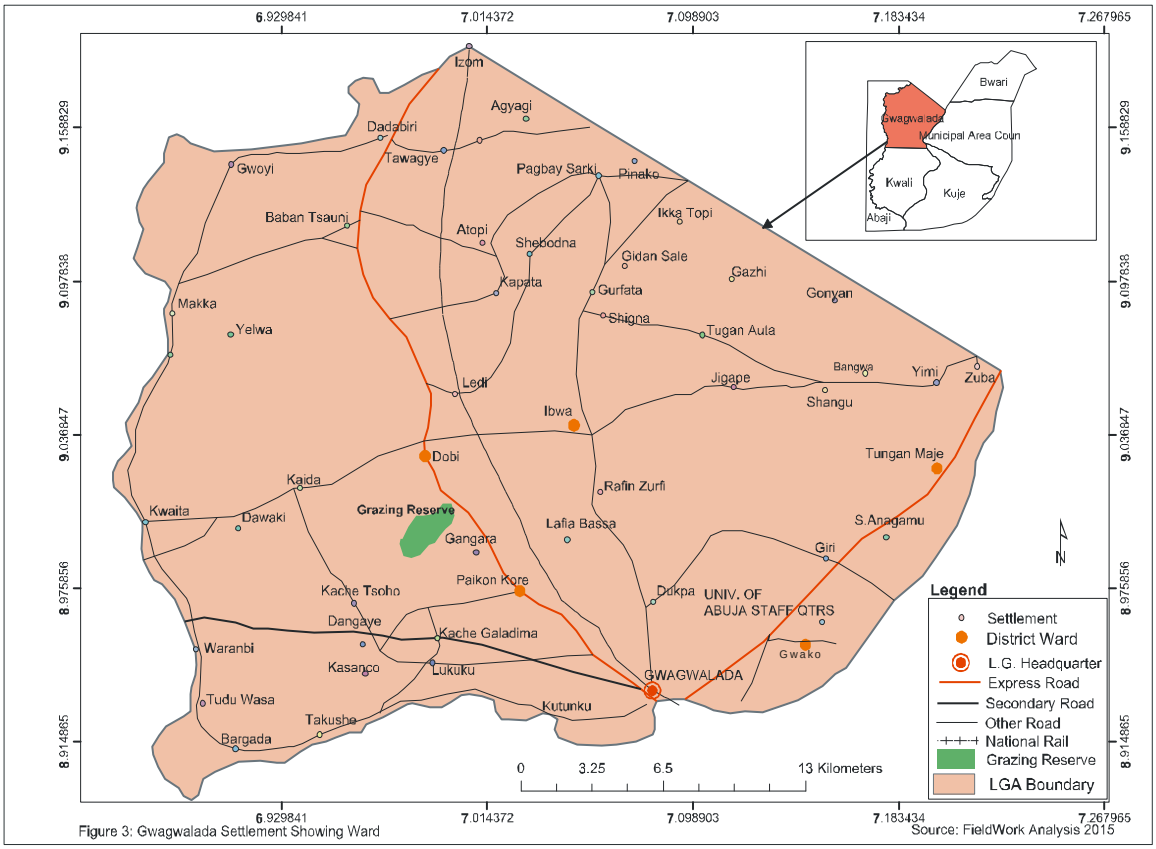
Lee, 2012; Boege and Turner, 2006; Gyuse and Ajene, 2006; Alubo, 2008; Okolie and Ugwu, 2011; Abbas, 2012; 2012; Muhammed, 2015; Nwoko, 2016; Bottazzi, 2016; Ukamaka et al., 2017) revealed trends of confrontations between the two groups aspiring towards incompatible values or competitive resources. The competition between these two agricultural land user groups, however, has oftentimes turned into a serious explicit and hidden manifestation of hostilities and social friction in many parts of Nigeria (Rashid, 2012).

The efficient and effective management of conflict is fundamental to the development of any society, but the prevailing situations in Nigeria constitute a reversal of this reality (Fasona&Omojola, (2005). Some cases of conflict are the cases of Modekeke in Osun state, the case of Agatu in Benue state, the case of Ohaji in Enugu state, the case Asakio in Nassarawa state, the case of village invading in southern Kaduna, the case of cow rustled in Gwagwalada, inter conflict in Adamawa, Benue, Bauchi, Enugu, Kebbi, Kogi, Kwara, Imo, Nasarawa, Oyo, e.t.c (International Group Crisis, 2009; Harrington 2009). However, Land-Use Conflict occurs when one land user is perceived to breach the rights, values, or amenity of another and it constitutes great impediments to livestock production and farming practice, especially to the rural areas.

The goal of human development is to evolve and foster understanding, mutual respect, and the principle of giving and take, among others. This is to enhance security and safety for all to directly participate and be inclusively involved to make life better, dynamic, and respond to changing circumstances. This should be deliberately designed to avoid, mitigate or neutralize conflicts to accommodate and sustain collective interest for security and safety.

The studies thus aim to analyze Land-Use Conflict between Farmers and Pastoralists in Gwagwalada Area Council, Abuja, Nigeria.

II. The Study Area



Source: Fieldwork Analysis, 2019

Figure 1: The study area Gwagwalada showing wards

The study area is Gwagwalada Area Council. It is located in the North-Central part of Nigeria and North-West of FCT Abuja. (Figure1). It located between Latitude 8° 56' N and 9° 34' N of the equator and

Longitude 7° 04' E and 7° 08' E of the Greenwich Meridian. It produced a population figure of 157,770 (National Population Commission, 2006). It has a landmass of 1,043 square kilometers and is bounded by Abuja Municipal Area Council (AMAC) and Kaduna in the North, Kwali on the South, Niger, and Abaji on the West, and Kuje and AMAC on the East as shown in Figure 1. The vegetation of the area is within the guinea savannah. However, gallery vegetation exists along the banks of the streams and rivers. Activities of man such as farming, fuelwood, and grazing have affected the vegetation so much so that the vegetation is at various levels of cereal development. Economic trees such as Locust bean (*Parkiabiglobosa*) Baobab (*Adansonia-digitata*) and Lime tree (*Isoberlinadoka*) are present. Grasses of various types ranging from short to tall grasses are available. The natural state of these vegetation has been tampered with by man's activities such as cultivation, over-grazing, and bush burning, thus changing the original vegetation so that climatic climax is not attained instead we have a Plagio-climax in the area. (Lyam, 2000). The climate of the area is characterized by two seasons. The wet season commences around mid-April to the later part of October while the dry season spans from November to early April. This climatic belt is generally very warm and humid. The mean temperature ranges between 26^{O}C and 36^{O}C. Temperatures are high during the day especially in the months of March and April. The hottest months are March and April while the coolest months are December and January. The mean annual rainfall is between 1120mm and 1500mm, Rainfall is accompanied by lightning and thunderstorm of high intensity, particularly at the beginning and end of the rainy season. Lafia has a relative humidity of between 60-80%, and it falls within the guinea savannah kind of vegetation Akwa et al*.,* (2007).

III. Methodology

a) Research Design and Strategy of the study

The study adopted a field survey design. The choice of survey design was based on the objectives of the study, the types and sources of data, the method of data collection.

Data on Farmers' and Pastoralists' perception, were gathered through the field survey using a structured questionnaire and observation to elicit the following information.

The farmers' and pastoralists' perception of the causes and effects of land-use conflict on farming and grazing activities. The method of data that were adopted to achieve the objectives of this study were.

b) Reconnaissance/Pilot Survey

The researcher carried out a reconnaissance survey from 7thoct – 10th November 2019 to be well acquainted with the study area. During the investigation, the researcher was opportune to meet all the relevant people such as head of village farmers (Sarkinnoma) and head of Fulanis (Sarkinfulanis), informants, stakeholder's that would, in any way, assist in the analysis of the land-use conflict between farmers and pastoralists in the study area. Besides, the pilot survey helped the researcher to have in-depth knowledge of the study area for 120 days (8th October to 6th November 2019) to distribute the questionnaire and interview the respondents with the help of field assistance. Also, to seek their support and cooperation Validation of the instrument.

Relevant data were collected with the aid of a structured questionnaire and personal interview and observation methods. The test-retest method was used to determine the reliability of the instrument. The data collection instrument which is the main schedule to be used in collecting data on the field is designed using a combination of subjective; multiple choices of questions were set up. The validation of the field research items was done by Senior lecturers of the Geography Department, Nasarawa State University. Keffi

Reliability: To ensure the reliability of the instrument, the test re-test method was adopted.

c) Target Population of the study

The Gwagwalada area council had a projected population of 232,350 as of 2019. The target population for this study is the small household Farmers/Herdsmen in Gwagwalada area councils. There are forty-nine (49) villages identified in the Gwagwalada area council.

d) Sampling Frame and Selection of Samples

The total population of the 10 sampled wards in Gwagwalada Area Council was projected at 292,350 (Projected, 2019). It comprises of Paiko-Kore with 22,500, Dukpa had 12,000 Zuba had 62,500, Kutunku had 14,750, Ibwa had 16,900, Quarters had 18,500, Central 68,700 while Dobi, Tunga-Maje, and Gwako had 31,500, 29,100, and 15,900 respectively. However, the target population of this study is the population of localities (Wards) in the sampled wards where land-use conflict between farmers and pastoralists often occurred (Table 2)

Table 2: Selected Wards of the study Area

Gwagwalada Wards	Population 2006	Projected Population 2019	Sample Size	
			Farmers	Pastoralists
Central	38,967	68,700	76	18
Dobi	17,046	31,500	35	08
Dukpa	5,322	12,000	13	03
Gwako	8,453	15,900	18	04
Ibwa	8,675	16,900	19	05
Kutunku	7,324	14,750	16	04
Paikon-Kore	11,876	22,500	25	06
TungaMaje	18,473	29,100	32	08
Quarters	8,090	18,500	20	05
Zuba	33,544	62,500	68	17
			322	78
Total	157,770	292,350	400	

IV. Results and Discussion

Table 2: The Major or Minor causes of conflict

Causes of conflict	Farmers ◄——► Pastoralists	Freq.	Mean	Freq.	Mean
Contamination of the stream		31	1.9	14	0.9
Land tenure and land use practice		33	2.1	01	0.1
Blockage and reduction in size of stock routes and access to water point		41	2.6	11	0.7
Commercialization of crop residues		20	1.3	00	0.0
Limited use of improved pasture and feeds		28	1.8	10	0.6
Traditional beliefs and practices		26	1.6	04	0.3
Sexual harassment of women		06	0.4	01	0.1
Theft of cattle		07	0.4	08	0.5
Poor land and soil conservation measures		24	1.5	06	0.4
Non-observation of rules and regulations		32	2.0	00	0.0
Poor state of the existing grazing reserves		05	0.3	10	0.6
Zero grazing of fallow land		15	0.9	02	0.1
Inadequacy of the existing farming land		44	2.8	00	0.0
Indiscriminate bush burning		06	0.4	11	0.7
Others		04	0.3	00	0.0
Total		322	20.5	78	5.0

Source: Field Survey, 2019
≤ 0.4 = Minor ≥ 0.5 = Major

Table 3: Using Wilcoxon Sum Rank Test (WSRT) Analysis to evaluate the causes of land-use conflict between farmers and pastoralists in Gwagwalada Abuja, Nigeria (n=400)

Causes of land-use conflict	Farmers	Pastoralists
Contamination of the stream	31	14
Land tenure and land use practice	33	01
Blockage and reduction in size of stock routes and access to water point	41	11
Commercialization of crop residues	20	00
Limited use of improved pasture and feeds	28	10

Traditional beliefs and practices	26	04
Sexual harassment of women	06	01
Theft of cattle	07	08
Poor land and soil conservation measures	24	06
Non-observation of rules and regulations	32	00
Poor state of the existing grazing reserves	05	10
Zero grazing of fallow land	15	02
Inadequacy of the existing farming land	44	00
Indiscriminate bush burning	06	11
Others	04	00
Total	322	78

Source: Field Work, 2019

n1=	15
n2=	15
Sum=	322
Expectation	232.5
Std. Error	24.109127
t-stat.	3.7122871
p-value	0.0001027

Source: Field work, 2019

The causes of conflict were classified into two scales namely; Major (mean= >0.6) and Minor (mean= ≤0.5). Table 4.5.1 shows a high mean(x) score on the factors causing land-use conflict for Farmers such as; Blockage and reduction in the size of stock routes and access to water point seem major causes on farmers=1.4 and pastoralists=2.0, Traditional beliefs and practices on farmers=1.0 and pastoralists=1.3, Limited use of improved pasture and feeds on farmers= 0.9 and pastoralists=1.1 and so on. On the contrary, Sexual harassment of woman seems a minor issue to the farmers (mean=0.4) while pastoralists see it as a major (mean=1.1), Theft of cattle seems a major to pastoralists (mean=1.4) while farmers are opposite of (mean=0.4), Contamination of the stream both parties tally on the mean of 1.0, Inadequacy of the existing farming land (mean=0.8) and pastoralists (mean=0.0), and so on. The view of the farmers and pastoralists agreed on some issues and disagreed on others as shown in figure 2. The inference of this shown problems because their view seems parallel and all stakeholders need to be involved for a lasting solution.

Effect of conflict in Gwagwalada Area

Council	Farmers	Mean	Pastoralist	Mean
Reduction in output and income of farmers	52	5.2	2	0.2
Erosion	33	3.3	0	0
Loss of lives / Cattle rustlers	25	2.5	35	3.5
Displacement of farmers / fulanis	48	4.8	15	1.5
Loss of houses and properties	24	2.4	19	1.9
Destruction of crops	76	7.6	2	0.2
Inability to remit loan	0	0	0	0
Allocation of the pattern of social	26	2.6	2	0.2
Loss of product in storage	31	3.1	3	0.3
Others	7	0.7	0	0
Total	322	32.2	78	7.8

The effects was classified into two scales namely; Major (mean= >0.5) and Minor (mean= ≤0.5). Table 4. shows a high mean(x) score on the effects of land-use conflict for Farmers such as Destruction of crops (mean=3.6), follow by mean=2.8 on Displacement of farmers/Fulanis, follow by mean= 2.4 on Loss of house and properties, follow by mean=2.2 on Reduction of output and income of farmers, while the mean of 2.1;1.6;1.3; and 1.1 on Loss of product in storage, Allocation of the pattern of social amenities, Erosion, others respectively. But, the farmers' response to Loss of cattle/ lives as a minor effect (mean=0.4) and inability to remit loan (mean=0.0). On the other hand, the pastoralist's Major effects of the conflict were; mean=5.1 on the loss of lives/cattle, follow by mean=4.8 on Loss of houses and properties and follow by mean=4.7 on Displacement of Fulanis, but Reduction of output and income of farmers, Loss of product in storage, Allocation of the pattern of social amenities, Inability to remit loan, Destruction of crops and Erosion all serves as Minor effects to the pastoralists. Hence, understanding the peculiarities and exploiting opportunities inherited in the Gwagwalada area council in FCT Abuja, Nigeria can produce greater prospects for effective, efficient, and sustainable conflict resolution strategies in enhancing the farmer-nomad relationship.

Wilcoxon Sum Rank Test (WSRT) analysis shows that there is sufficient evidence to suggest that there is a difference between the farmer's perception and pastoralist's perception in terms of land-use conflict approach in the study area. In Wilcoxon Sum Rank Test we don't need to assume that the population of farmers and pastoralists is normally distributed (robust). The techniques also show the level of causes of conflict and how much it affects the lives and livelihood of the Gwagwalada community at large. The application of the t-test was to support and validates the Wilcoxon Sum Rank Test and to void complications during data interpretation.

The above analysis showed that both farmers and pastoralist's responses opined that Blockage and reduction in the size of stock routes was a major problem in the study area. This rhyme with the idea of Reichel, (2010) when he sees land-use conflict as a situation in which two or more parties strive to acquire the same scarce resources at the same time. The denial or blockage and reduction in the size of farm size or stock routes have laid to boundary trespasses and the claimed correlate with the farmer's view on denial access to their farmland that was converted to grazing reserves during 1980s. The second most common reason for the conflict was over the Theft of cattle, which exclusively occurs among the two parties. In the past fifteen years, it appeared that there was more conflict related to land use between farmers and pastoralists. However, as the value of land increases due to population pressure, agricultural commercialization, and urbanization, it is expected that all the stakeholders from top to grassroots actors should collaborate and achieve a lasting solution over time. Therefore, if land-use rights are not clearly defined, there could be more cases of land conflict in the study area in the future.

V. Conclusion

This study concludes that; land use, water resources, and grazing resources were the major courses of conflict between farmers and pastoralists; most of the conflict arises from competition over the use of land use, water, and grazing. This has to do with a combination of factors principally resulting from a deficiency in the overall national agricultural development strategy. This was manifested in the corrosion of the land use rights of the grazing resources, poor legislative structure, poor campaign and awareness measures, slow uptake of agricultural technology especially livestock production and management practices and poor land and soil conservation measures, and failure to recognize the impact of grassroots actors.

Excessive use such as overgrazing in the common land was likely to cause conflicts among the communities living in the area. Crop damage during grazing, animal theft, blockage of water points, and nomadic grazing were the major causes of land clashes among the farmers and pastoralists. Effects of such conflicts are known to cause loss of lives, damage of properties, and disappearance of peace and harmony. However, it was discovered that there were recurrent clashes of interests, values, and needs between the host farmers' communities and the nomadic cattle herders in the study area.

The study recommends that the role by the community leaders in resolving land conflict is very crucial; Sensitization of stakeholders, farmers and herdsmen alike – on the need for mutual co-existence and peace; this would help to forestall needless provocations and opportunistic violence; Poor extension contact with livestock producers should be addressed. This could be through the provision of proactive and well-trained extension personnel. Extension personnel in the employment of the Gwagwalada Area Council can be trained to deliver livestock extension messages to pastoral communities. Finally, Government should amend the land use Act and come up with new policies to benefit both the farmers and pastoralists

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Integrated Approach to the Auto-Ecological Study of Presence of *Brassica incana* Ten. in the Gargano Promontory (Puglia, Southern Italy), on the Adriatic Side of the Italian Peninsula

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Abstract- The study deals with the finding of new localities of *Brassica incana* Ten. in the Gargano promontory; *B. incana* is a species of the European flora occurring in Italy and in the Balkan area, assessed as Data Deficent (DD) according to IUCN criteria. The presence of the species in Apulia was based on old records not recently confirmed. The new Gargano's finds are limited to the imposing and inaccessible cliff of Monte Pucci, a small promontory placed on the coast between Rodi Garganico and Peschici (FG). *B. incana* grows on the edge of small terraces of the cliff with other typical rupicolous plants such as *Matthiola incana, Anthyllis barba-jovis*, *Allium commutatum*, *Campanula garganica*, *Capparis rupestris* subsp. *rupestris* and *Brachypodium retusum*. Geological and pedological analyses have detected the stratigraphic units that form the substratum of *B. incana* habitat (Scaglia formation-Upper Cretaceous-; Peschici formation-Middle Eocene), which turn out to be unique in the Gargano promontory. Based on these data, the study shows that *B. incana* is linked to specific geological and pedological substrates (soils rich of SiO2).

Keywords: *chasmophytic vegetation, distribution range, rock stratigraphy, species auto ecology.*

GJSFR-H Classification: *FOR Code: 060299, 070199*

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Keywords: chasmophytic vegetation, distribution range, rock stratigraphy, species auto ecology.

I. Introduction

The research focuses on the analysis of Brassica *incana*, a species of the Apulian flora, whose presence (Conti, 2005; Bartolucci et al. 2018) is based on several reports for the Tremiti Islands (Béguinot 1906; De Marco et. 1984, Maggioni et al. 1996, 2008, Licht-2020) and another for Salento (Groves 1887), considered extinct in the latest update of "Flora del Salento" (Mele et al. 2006). For the Gargano it was not listed in the Prodromus Florae Garganicae by Fenaroli (1966-1974) but will then be described in a recent analytical flora (Licht 2008) documented by a herbarium sheet (MJG herbarium–Licht-2017) of samples collected from Peschici and San Menaio.

In light of these reports, certainly not exhaustive, and in consideration of a little known species in Italy, it was intended to deepen the knowledge of the populations present on the Gargano Promontory which, together with those of the Tremiti Islands, have phytogeographic value, being the only presences on the Adriatic side of the Italian peninsula.

Its distribution range in Italy is limited to the southern regions with its northern limit on the Adriatic side at the Gargano, it also occurs on the Tyrrhenian side in Tuscany (Bartolucci et al. 2018). The species also occurs along the coasts of the Balkan countries including Croatia (Maggioni et al. 1996; Snogerup et al. 1990), Slovenia, Bosnia Herzegovina, Serbia and Montenegro (Snogerup et al. 1990). Therefore, being a real amphi-Adriatic species, it is part of the conspicuous group of species that testifies the ancient paleogeological connections between Apulia and the Balkan peninsula. Furthermore, *B. incana* is part of a large group of eastern Mediterranean species that have their eastern limit in Albania (Proko 1988).

The interest of the research was to find a possible relationship with geological factors that explained the presence of the species so rare and localized on the Gargano.

a) Botany, taxonomy and ethnobotany of the species

Brassica incana is a suffruticose chamaephyte that reaches 150 cm in height with long and thick woody stems (up to 2 cm thick). The pubescent, whitish, poorly structured leaves have a soft and hairy texture due to the presence of hairs, generally simple and denser along the veins. The lower leaves (basal) have winged stalks (10 cm), smaller than the lamina that reaches remarkable size (8-15 x 12-25 cm), having a variable shape (lanceolate, lirate, auricolate or amplexicauli ovate) with margins irregularly denticulate; upper undivided leaves are gradually smaller. Flowers are grouped into racemes having a linear-lengthened development (10-30 cm) rich of many yellow flowers, bleaching in the dry (pedicels 10-25 mm; yellowish sepals 12-16 x 2-4 mm; yellow-bright petals 20-30 x 8-13 mm). The silique is arched (slightly compressed dorsally), more than 5 cm long; the seeds are 3-4 x 4-5 mm is conic 8-14 mm long, seedless rostrum. Flowering occurs in March-April. The chromosome number is 2n=18 (Ferrarella & al. 1980; Pignatti, 1982;

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2018). In the past, the species was described as a sub-variety [*B. oleracea* subvar. *incana* (Ten.) Cosson] (Tenore 1811-1815) or a variety of *Brassica oleracea* [*B. oleracea* var. *incana*(Ten.) Paol.] (Fiori 1896-1908), or even as a subspecies of *B. sylvestris* [*B. sylvestris* subsp. *incana* (Ten.) Onno] (Fiori 1923-1925). The recent taxonomy raises it to species value named *B. incana* (Pignatti 1982, 2018; Bartolucci et al. 2018). *B. incana* is an edible species; in Italy it is known by rural communities as cabbage or "wild" broccoli (Campania, Ischia, Calabria), but in the etno botanic literature there are no reports about uses as food, contrary to other species of the same genus, such as *Brassica nigra* (L.) W.D.J.Koch (Umbria, Apulia, Basilicata, Sicily and Sardinia), *Brassica rupestris* Raf. subsp. *rupestris* (Sicily), *Brassica tournefortii* Gouan (Sicily), *Brassica tyrrhena* Giotta, Piccitto & Arrigoni (Sardinia) (Biscotti et al. 2018). All the species of genus *Brassica*, especially *Brassica oleracea*, are considered to be possible ancestors of many cultivated vegetables (cabbages, broccoli, etc.) marketed all over the world; *B. incana* has also been studied as a potential relative of cultivated cabbages having probably crossbreed with *B. oleracea* (Dixon 2007; Hammer et al. 2013; Tsunoda et al. 1980; Gigante et al. 2012).

b) Italian distribution range

According to Flora d'Italia (Pignatti 1982), the species is recorded in Campania, Basilicata, Calabria, Apulia, Sicily (including the islands) and the Pontian Archipelago. Its occurrence were recently confirmed in Basilicata (Conti et al. 2004; Lucca et al. 2004), Calabria (Muscolo et al. 2017) and Sicily (Castellano et al. 2009). In the latter region, the species is present on the northern and eastern sectors of the island even if the old record of the species in Trapani was attributed to *Brassica villosa* subsp. *bivoniana*(Mazzola & Raimondo) Raimondo & Mazzola or *Brassica villosa* subsp. *drepanensis* (Caruel) Raimondo & Mazzola (Ottonello et al. 1958; Raimondo et al. 1991). Finally, several well-known occurrences in different Italian islands are known (Giglio, Ponza, Napoli archipelago, Aeolian archipelago, Tremiti, Pelagosa, and Pelagie Islands) (De Natale 2003). Therefore, the Italian distribution range of *B. incana* is disjointed and limited to some localities of the Tyrrhenian and Ionian sides such as Tuscany, Lazio, Campania, Basilicata, Calabria and Sicily; for the Adriatic side it is known only in Apulia (Conti et al. 2005; Bartolucci et al. 2018; Pignatti 2018). The Italian distribution is shown in Figure 1.

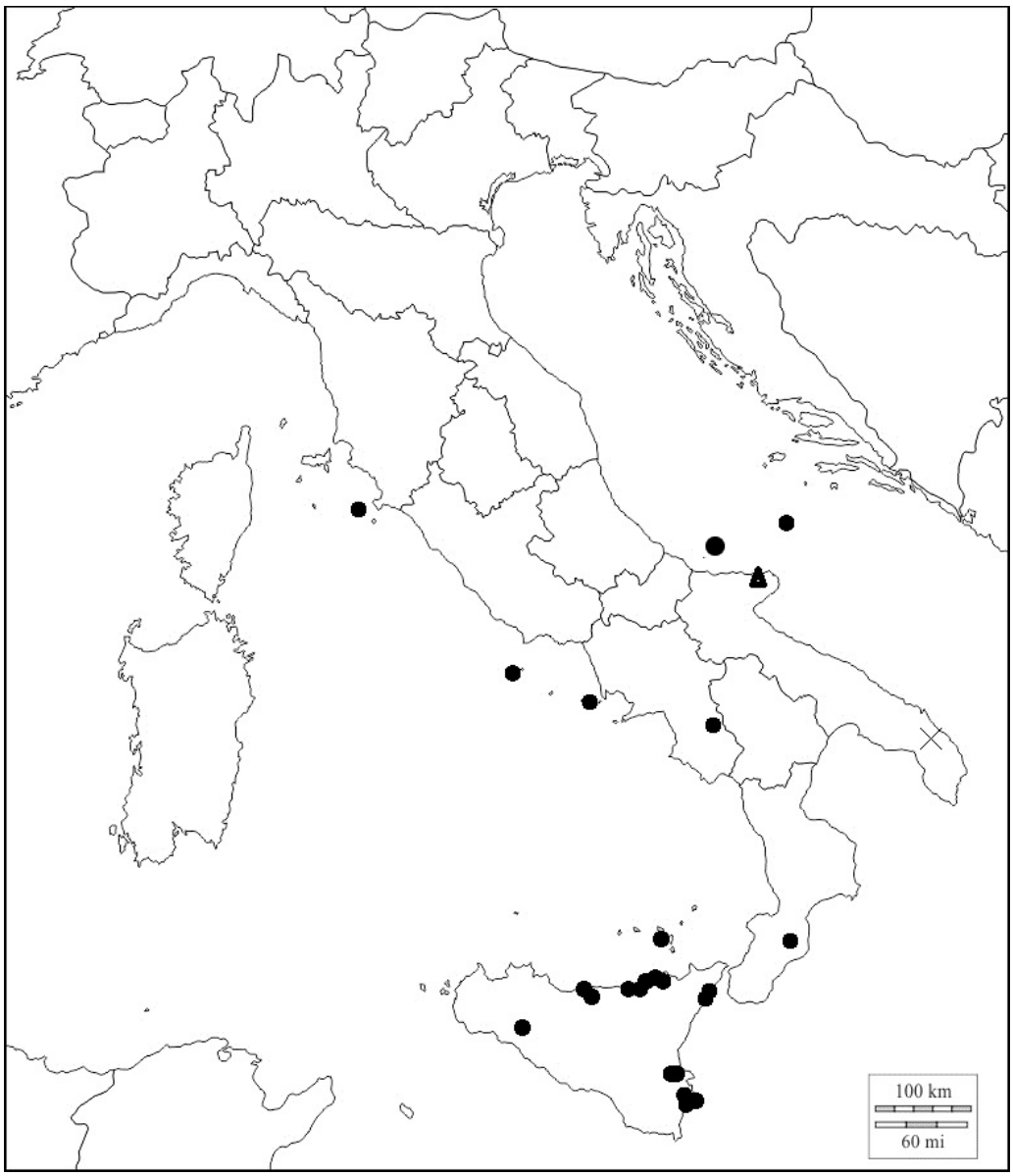

Figure 1: Distribution range of *B. incana* in Italy. The dot indicates the stations currently known; the X the stations where the species is extinct; with the triangle the new stations mentioned in this article.

c) *Ecological and phytosociological knowledge about Brassica incana Ten.*

According to literature, *Brassica incana* Ten. is a species usually linked to maritime and calcareous cliffs, from 0 up to 800 m a.s.l. (Snogerup et al. 1990; Pignatti 2018).

In the localities where it has been studied in details, it is linked to a low Mesomediterranean low subhumidbioclimate (Raimondo et al., 1991). It is also known as a Mediterranean chasmophyte, heliophylous, thermophilic and basophilic, generally thriving on nutrient-poor soils sometimes acidic (Raimondo 1997; Pignatti 1982) with slow and constant growth rates that are able to store water and nutrients. In phytosociological studies, the species is indicated as a characteristic species of the rocky vegetation of the alliance *Dianthion rupicolae* Brullo & Marcenò 1979, which brings together the chasmophytic communities, tending to be mesophilic and resistant to marine aerosol (Biondi et al. 2014; Mucina et al. 2016). This alliance belongs to the class *Asplenietea trichomanis* that in Mucina et al. (2016) is described as follows: "chasmophytic vegetation of crevices, rocky ledges and faces of rocky cliffs and walls of Europe, North Africa, Middle East, the Arctic archipelagos and Greenland. The *Asplenietea trichomanis* is a particularly heterogeneous class. These rupicolous plant communities differ not only in species composition, alpha diversity and ecology, but also in overall structure, prevailing life form, and evolutionary history. Especially in the

Mediterranean, the cliff habitats have served as refugia for plants to survive unfavorable climatic conditions as well as grazing pressure. There is a large number of plants exclusive to vertical rock, many of them being regional or local endemics." According to the Italian Prodrome, the class brings together the perennial casmophytic and non-nitrophilous communities that develop in the cracks of rocks, walls and faces (Biondi et al. 2014) sometimes with subalophile species typical of the class *Chritmo maritimi-staticetea* Br.-Bl. in Br.-Bl., Roussine & Nègre 1952 em. Biondi 2007 (Pignatti 2018).

In a phytosociological study carried out in Sicily, focused on the definition of the phyosociological role of *B. incana* (Castellano et al. 2009), the subassassociation *brassicetosum incanae* of the shrubby thermophilous association *Euphorbietum-dendroidis* Guinochet in Guinochet and Drounieau 1944 has been described.

II. Materials and Methods

After a careful examination of all the rocky coastal sites and cliffs of the promontory, from RodiGarganico up to Mattinata, the species has been found only in the ridge of Monte Pucci (northern Gargano), having particular geological conditions that deserved to be investigated with the help of geologists. The integrated approach (botany and geology) has thus made it possible to investigate thoroughly a little-known species, assessed as Data Deficient (DD), according to IUCN criteria (Kell 2011). The study of garganic localities has provided information on the biology of the species and an overview of the ecological conditions (particularly geo-pedological) to which the species is linked. The investigations were carried out in spring/summer 2019.

a) Geological setting and stratigraphic characterization of Monte Pucci area

Monte Pucci area represents a small rocky promontory abutting the Adriatic Sea, delimited by two alluvial plains named Calenella Plain on the west side and Clavia Valley on the eastern side. Along the coast, there are many inaccessible sea-cliffs that allow to observe the stratigraphic succession as well as the loci where *B. incana* has been detected (Fig.2). Along these sea cliffs, instability phenomena are quite frequent and gravity falls accumulate chaotic breccia bodies at the peak of the cliff (Martino & Mazzanti 2014).

Figure 2: The typical stratigraphic succession along the eastern sea-cliff of the Monte Pucci "Trabucco". Decametric olistolith occurs in a very thick breccia layer at the top of the succession. The well bedded intervals represent pelagic deposits interbedded in nummuliticcalciturbidite. Note that the vegetated part is associated to a very thin soil deveopped along some tight steps of the sea-cliff that correspond to thin layer of clay.
Inset: detail of the habitat of *B. incana*.

The Gargano Promontory consists of a thick pile of carbonate rocks formed during the Mesozoic and Cenozoic Periods in different depositional environments of a huge carbonate platform called Apulia Carbonate Platform (ACP) (Bosellini et al. 1999; Borgomano 2000; Morsilli et al. 2004, 2017b; Morsilli 2016). In the Gargano Promontory, contrary to other parts of the Apulia Region, it is possible to observe the transition between the shallow-water inner platform facies and the deep-water basinal successions. Particularly, in the study area of Monte Pucci only basinal facies crops out. Here, the stratigraphy is quite simple and only two stratigraphic units can be detected: the Scaglia Formation (Upper Cretaceous) and Peschici Formation (Middle Eocene) separated by an unconformity that represents a long hiatus of about 40 My (Morsilli et al. 2017a). The Scaglia Formation (from Cenomanian to Santonian p.p.) – consists of thinly bedded (5 to 30 cm) white lime mudstone, generally with layers or nodules of brown to orange cherts. In some outcrops, some breccia or

calciturbidite beds occur related to a coeval submarine gravity-flow. The thickness of this stratigraphic unit is about 90-100 m in this area. This unit was deposited in a relatively deep basin and consists mainly of pelagic accumulation of calcareous nannoplankton and planktonic foraminifera (Bosellini et al. 1999). The Peschici Formation (from Lutetian to Bartonian) - consists of various lithofacies, mainly related to gravity flow processes, deposited in a slope to base of slope setting. The main lithofacies consists of meter-thick coarse calciturbidites rich in large nummulitids, alternating with "chalky" lime mudstones and fine-grained calcarenites. Furthermore, breccia bodies with clasts of shallow-water Eocene (corals) or Cretaceous origin (rudists) are also present. Along the main road climbing to Monte Pucci watching tower from Calenella Plain, the complete stratigraphic succession crops out (Borrelli 2017; Morsilli et al. 2017a).

Along the sea-cliff, re-sedimentation processes are clearly evident, as the decametric well stratified olistolith embedded in the breccia layers that crops out close to the "Trabucco" of Monte Pucci. The unconformity separating the Eocene deposits from the underlying deep-water Cretaceous ScagliaFm is not a transgressive contact, as previously interpreted, but a submarine unconformity onlapped by gravity-displaced and pelagic sediments (Bosellini et al. 1999; Morsilli et al. 2004). Therefore, it is not yet clear which mechanisms were involved in the formation of this erosional contact, but a slump scar or the prolonged activity of deep-sea currents could explain this unconformity (Bosellini et al. 1999).

b) Survey methodology and analysis

The samples were collected in the period of full development of the plant, in which all diagnostic characters are visible; the taxonomic identification was done according to Flora d'Italia (Pignatti1982; Pignatti 2018). The updated checklist of the vascular flora native to Italy was used to assess the Italian distribution range (Bartolucci et al. 2018), while for the European distribution we fallowed Snogerup et al. (1990). The localities of occurrence have been geo-referenced by a GPS (WGS84: Datum). Few intact samples were taken (the species is widely subject to attacks by *Pierisbrassicae*)and collected in the only accessible point of cliff, represented by the edge of the upper terrace of the cliff. A herbarium sheet is stored at the *Herbarium Anconitanum* (ANC) of the Polytechnic University of Marche. All other occurrences of the species on the cliff were detected through UAV (DJI Mavic Pro) with 4k resolution.

In order to assess the participation of the species in habitat of conservation interest according to the Habitats Directive, we consulted the Italian Interpretation Manual of the 92/42/CEE Directive (Ministry of the Environment 2016) while to understand the role of the species in phytosociological terms, we referred to the Vegetation Prodromeof Italy (Biondi et al. 2014). For the bioclimatic classification of the Gargano's localities we followed Pesaresi et al. (2017).

The video analysis permits to reconstruct the stratigraphy and morphological features of the sea-cliffs, as bedding planes and thickness, fracture and occurrence of the main facies of the stratigraphic unit that crops out in this area. Changes in bed thickness, as well as the presence of thin marly beds, create some morphological steps or narrow terraces along the vertical cliffs, where very thin soil horizon can accumulate and retain by vegetation(Fig. 2).

The geological characterization of the Monte Pucci area has been conducted with the traditional methods that include a geological survey and a stratigraphic-sedimentological analysis of the outcropping part of the succession. Rock samples have been collected and studied in thin section under plane-polarized microscope, to characterize the composition, texture and fossil contents.

Due to the occurrence of a single stratigraphic unit, we collected only one soil sample (GPS position), successively analysed at the Department of Physics and Earth Science of the University of Ferrara. The soil sample has been analyzed in terms of texture, composition and geochemical elements.

For the geochemical analysis, after 12 h of heating at 550°C (to remove the organic matter), the sample was powdered in an agate mill and approximately 4 g of powder was hydraulically pressed with boric acid to obtain powder pellets. Simultaneously, a sample aliquot of 0.5–0.6 g was further heated for approximately 12 h in a furnace at 1000 °C to determine the loss on ignition (LOI). This parameter measures the total concentration of volatile substances contained in the sample. The Wavelength Dispersive X-Ray Spectrometry (WDXRF) analysis of the powder pellets was performed using an ARL Advant'X spectrometer Thermo Scientific (Waltham, MA, USA). Calibrations were obtained analysing certified reference materials, and a matrix correction was performed according to the method proposed by Trail and Lachance (1966). Precision and accuracy calculated by repeated analyses of international standards with matrices comparable to the studied samples (Di Giuseppe et al. 2014) were generally better than 3% for Si, Ti, Fe, Ca and K, and 7% for Mg, Al, Mn and Na. For the trace elements (above 10 ppm), the errors were generally better than 10%.

III. Results

In the Gargano Promontory, the species has been found only in two localities occurring in the same complex of cliffs of the Promontory of Monte Pucci, near Vico del Gargano (N41°56.806', E15°59.610'; N41°56.716', E15°59.423'), from 30 to 83 m a.s.l., on

crag (indicated with the triangle in Fig.1). Both localities are north-faced. The habitat of the species is circumscribed to small rocky terraces along steep cliffs exposed to marine aerosol and humid sea currents, through which it satisfies most of its water needs. It forms poor plant communities with other rupicolous species such as *A. commutatum*, *Anthyllis barba-jovis*, *Matthiola incana*, sporadically *Brachypodium retusum*, *Campanula garganica*, and *Capparis rupestris* subsp. *rupestris*. We found some plants on the plans of the cliff on small cones of recent erosion as well. According to the Italian Interpretation Manual of the 92/42/CEE Directive Habitats (Ministry of Environment 2016), the species is a floristic element of the habitat 8210 "Calcareous rocky slopes with chasmophytic vegetation" and specifically of the subtype 62.14 "Community of southern Italy (*Dianthion rupicolae*)".

The main components of soils found in the Monte Pucci sample are mostly related to a siliciclastic composition with abundant Silica and Al_2O_3 and subordinate CaO (Fig.3). The substrate where the soil was formed consists of pure carbonate rock. Only some very thin clay layers interbedded in some part of the succession occur. The soils where the species thrives are a few centimetres thick and they rises from the activity of winds, which deposits fine and inconsistent particles where the plant roots develop.

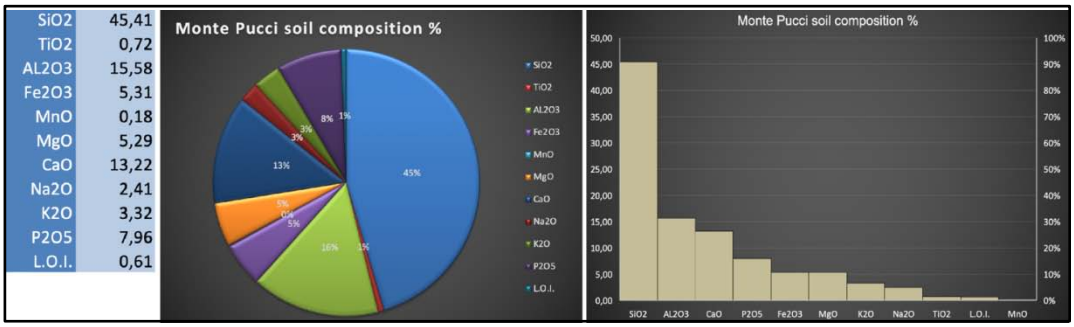

Figure 3: Main components of the Monte Pucci soil

IV. Discussion

As regards the bioclimatic classification, the Gargano localities are part of the Mediterranean macroblioclimate (Pesaresi et al. 2017) like all other localities known in Italy. On the contrary, the localities of occurrence in the Balkan peninsula are mainly classified in the temperate macrobioclimate. The Gargano localities, as well as those in Tuscany and Campania, are part of the lower mesomediterranean bioclimate while the Calabrian and Sicilian ones, are part of the thermomediterranean bioclimatic belt (Syracuse). Therefore, the species grows with different bioclimatological characteristics, ranging from the more mesophile conditions of the temperate macrobioclimate to the warmer ones of the Mediterranean macrobioclimate.

Trace element analysis shows how the sample has abundant Ba, followed by other elements such as Ce, Cr and V with concentration around 100 ppm (Fig.4). It is interesting to note as, contrary to what we expected, the soil composition reveals a very high SiO2 concentration. A possible explanation of this high content in silica can be related to the presence of nearby siliciclastic sand beaches of the Calenella Plain, where very thin sand composed of quarz, K-feldspar and skeletal carbonate shells occur. During wind storms, this very thin sand can be blow out from the beach and transported for a short distance along the sea-cliff and trapped in the vegetation root and incorporate into the soil matrix. Another source of silica can be related to the fore mentioned clay layers, but the inaccessibility of the sea-cliff prevented sampling. The geology of the Gargano Promontory is characterised by the presence of silicon dioxide (SiO2) occurring as oval nodules and/or beds in carbonate rocks: this abundance of silicon dioxide tends to acidify the soils, a condition that explains the presence of typically acidophilic plant species and communities (Biondi et al. 2008).

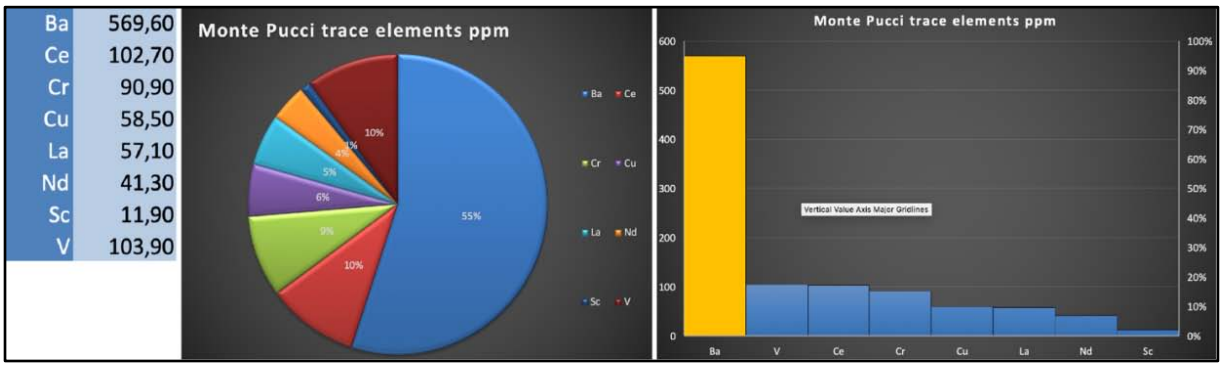

Figure 4: Trace elements concentration of Monte Pucci soil

V. Conclusions

This ecological study of the localities of occurrence of *Brassica incana* in the Gargano promontory has confirmed what was already known for the habitat characteristics of the species, such as its heliophilia (the species is the first one that colonizes small terraces giving rise to small communities), its presence on maritime rocky cliffs and the calcareous nature of the substrates. The localities from Gargano also reveal a link with generally acidic microsoils with incomplete stratigraphy and poorly structured, vertically developed and exposed to the north. They are made up of pure carbonate rock, with marginal presence of very thin clays and high concentrations of SiO2 along with oxides of aluminium (Al2O3) and oxides of calcium (CaO), due to the original stratigraphy that the Gargano presents only in the ridges of Monte Pucci.The investigations on the Gargano, with an integrated approach of study, have revealed that the localized presence of the species is explainable for its link to precise geological units.

The topography of the sitescharacterised by steep cliffs completely inaccessible, has not alloweda detailed surveys of the plant communities yet, thus makinga phytosociological classification impossible.

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Effects of Climate Variability on Maize Yield in Wukari Local Government Area of Taraba State, Nigeria

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Abstract- This study assessed the effects of climate variability on Maize yield in Wukari Local Government Area of Taraba State between 1999 and 2018. The research design employed in the study was an ex-post facto and analytical design. Hence, the study is a quantitative study that provides statistical data as empirical evidence and produces descriptive and informative sceneries of the topic study. Based on the objectives of this study and data analysis, the results revealed an increasing trend in average annual maximum temperature in the study area, with 62 percent variability, and a deceasing trend in average annual minimum temperature, with 44 percent variability. More so, the results revealed an almost uniform but increasing trend in average annual rainfall in the study area between 1999 and 2018, with a 37 percent variability. Furthermore, results of the trend analysis revealed an increasing trend in maize yield in the study area, with 50 percent variability. The correlation analysis revealed a non-statistically significant strong positive linear relationship ($r = 0.088$, sig. $0.712 > 0.05$) between the average rainfall and average temperature in the study area.

Keywords: *climate, variability, maize, rainfall, temperature.*

GJSFR-H Classification: *FOR Code: 960399*

Strictly as per the compliance and regulations of:

Effects of Climate Variability on Maize Yield in Wukari Local Government Area of Taraba State, Nigeria

Gayos A. Garba Umar [α] & Iliyasu M. Anzaku [σ]

Abstract- This study assessed the effects of climate variability on Maize yield in Wukari Local Government Area of Taraba State between 1999 and 2018. The research design employed in the study was an ex-post facto and analytical design. Hence, the study is a quantitative study that provides statistical data as empirical evidence and produces descriptive and informative sceneries of the topic study. Based on the objectives of this study and data analysis, the results revealed an increasing trend in average annual maximum temperature in the study area, with 62 percent variability, and a deceasing trend in average annual minimum temperature, with 44 percent variability. More so, the results revealed an almost uniform but increasing trend in average annual rainfall in the study area between 1999 and 2018, with a 37 percent variability. Furthermore, results of the trend analysis revealed an increasing trend in maize yield in the study area, with 50 percent variability. The correlation analysis revealed a non-statistically significant strong positive linear relationship ($r = 0.088$, sig. $0.712 > 0.05$) between the average rainfall and average temperature in the study area. More so, the correlation analysis revealed also revealed a non-statistically significant weak negative relationship ($r = -0.072$, sig. $0.762 > 0.05$) between average rainfall variability and maize yield in the study area. A statistically significant moderate positive linear relationship ($r = 0.564$, sig. $0.010 < 0.05$) was found between average temperature and maize yield in the study area. The linear regression analysis revealed that 33 percent (r-squared: $r^2 = 0.333$)of the variation in maize yield is explained by the variation in rainfall, and temperature between the periods of 1999 and 2018 in Wukari Local Government Area of Taraba State. Hence, rainfall and temperature affect maize yield in the study area by 33 percent. The study thus recommended that farmers should adopt climate change and variability mitigation and adaptive measures. These include the use of resistant and drought tolerant species. In addition, there is need for the Ministry of Agriculture and Taraba State Agricultural Development Programme to educate farmers and farm agents on the realities and effect of climate change and variability, as well as adaptive measures that can be taken. These include better and practicable environmental policies, improved agricultural techniques, and alternative source of water which will include irrigation farming, and mulching, vis-à-vis creating sustainable food security in the long run.

Keywords: climate, variability, maize, rainfall, temperature.

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I. Introduction

Climate is the characteristic condition of the atmosphere near the earth's surface at a given place or region over a considerable period of time, usually 35 years and above (The Intergovernmental Panel on Climate Change [IPCC], 1992). Tim (2000) defines inter-annual climate variability as the observed inter-annual difference in value of specific climate variables within an averaging period (typically 30 years). Thus, climate variability can be regarded as variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Rainfall variability impact analysis is a way of looking at the range of consequences of a given rainfall event or change on given spatial phenomena (Chiew, 2002).

Agriculture is highly dependent on climate and a critical part of the economy in most developing countries in Africa. Climate change and its variability are emerging as major challenges to agricultural development with the increasingly irregular and erratic nature of weather conditions placing an additional burden on food security and rural livelihoods (Food and Agriculture Organization (FAO), 2009). Climate variability has a direct and, in most cases, adverse influence on quality and quantity of agricultural crop production. The climate of an area is highly correlated to the crops cultivated and thus predictability of climate is imperative for planning of farm operations (Sowunmi, 2010).

According to Intergovernmental Panel on Climate Change (IPCC, 2007), "Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)". While, climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Climate change and variability are closely linked in the climatic system, with long term scale climate change manifesting itself with episodes being observed in short term climate variability. Instances of climate variability consist of seasonal, annual and inter decadal variation in temperature and

rainfall, extensive droughts, floods and conditions that result from periodic El Nino and La Nina events. Due to their close association, climate change and climate variability are concomitantly used together in research as well as in policy. Thus, in most cases extricating the impacts of climate change and climate variability has largely been difficult especially in the agricultural sector (Bizuneh, 2013).

Climate variability is expected to increase with global warming. Global warming refers to observed increase in temperatures over the last 50 years as a result of increased greenhouse concentrations in the atmosphere (Solomon, 2007). In the midst of the rise in global temperatures, changing local rainfall patterns, warming seas and melting of ice caps have been witnessed (IPCC, 2007). Furthermore, global average temperatures are expected to increase by between 1.4°c and 6.4°c by 2100. This increase is above threshold limit of 3oC beyond which it becomes impracticable to avoid dangerous interference with the global climatic system (World Trade Organization [WTO] & United Nations Environmental Programme [UNEP], 2009). This average is anticipated to be higher throughout Africa and Central Asia. In Africa average temperature is projected to rise 1.5 times more compared to the global level. Countries near the equator many of which are developing, are likely to experience unbearable heat, more frequent droughts and ruined crops, exacerbating the hunger crisis (Food and Agriculture Organization [FAO], 2012; WTO & UNEP, 2009). However, increasing global temperature may have mixed outcomes, where crop production may increase in temperate regions but reduce yields in tropical regions (WTO & UNEP, 2009).

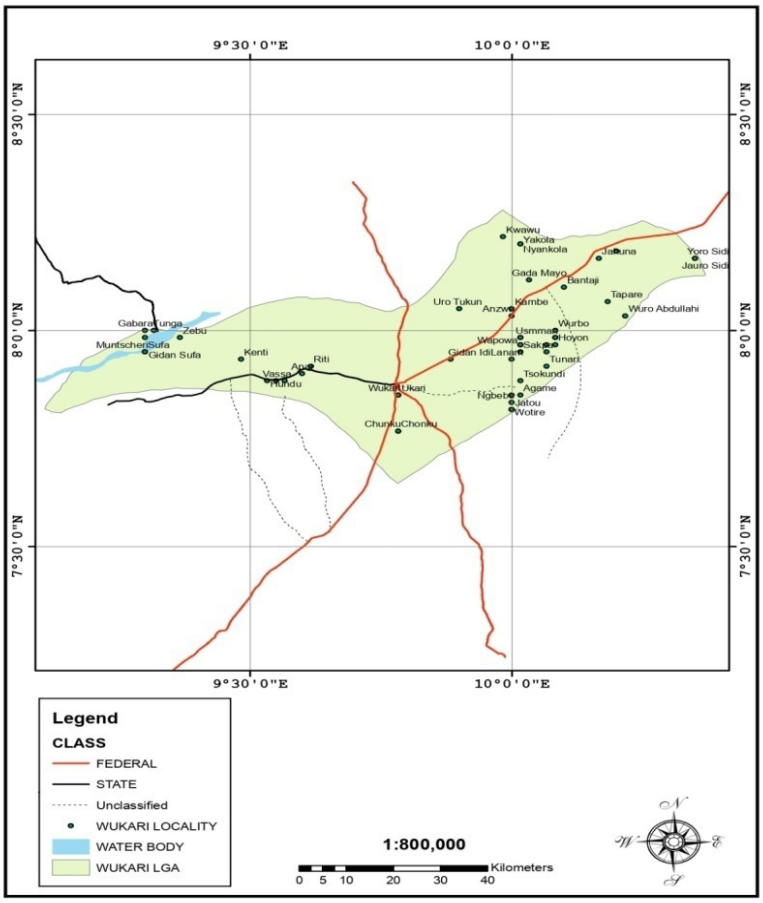
Beside the changes in temperature, over the years, rainfall patterns have changed, with cases of heavy rainfall at crop maturity and droughts occurring at critical stages of crop growth being common (Birech, Freyer, Friedel, & Leonhartsberger, 2008). These changes are likely to severely, compromise crop production and food security with colossal economic consequences in many African countries especially in sub Saharan Africa (Gregory, Ingram, & Brklacich, 2005). There is likelihood that changes in temperature and rainfall patterns, will affect the potential of crop production (Stern, 2007). The effects of climate variability on crop production could be direct or indirect. Directly the effect is through changes in temperature and precipitation that affect the timing of crop development (Joshi, Maharjan, & Piya, 2011; Gbetibouo & Ringler, 2009; Gregory *et al.,* 2005). Rising temperatures are likely to reduce crop production in the long-term especially through reduction in the number of reliable crop growing days while changes in precipitation patterns are likely to increase short term crop failures and long term production declines (Peiris, Crawford, Grashoff, Jefferies, Porter, & Marshall 1996; IPCC, 2007; Joshi *et al.,* 2011).

Increase of these events as experienced and projected in Sub Saharan Africa are likely to have adverse effects on crop production and food security raising the vulnerability of most developing countries (Mirza, 2003; Wassmann & Dobermann, 2007; Schmidhuber & Tubiello, 2007). It is thus on the premise of this background that the study was aimed at assessing the effects of climate variability on maize (*Zea mays*) yield in Taraba State.

II. Materials and Methods

a) The Study Area

i. Location and Position



Source: AGIS, 2019

Fig 1: Map of the study area

Taraba State is located in the North-East geographical zone of the country, with its head-quarters in Jalingo. It has sixteen (16) Local Government Areas (LGAs). The State has a total land mass of 51,000-kilometre square. It lies roughly between latitude $6^{0}30^{1}$ and $9^{0}36^{1}$N and longitude $9^{0}10^{1}$ and $11^{0}5^{1}$E. It is bounded on the North-East by Adamawa State and the West and South-East by Plateau and Benue States respectively. On its east border is the Republic of Cameroun. According to the 2006 Census figures released by the National Population Commission (NPC), Taraba State has a population of 2, 294, 800 people (NPC, 2006).

Wukari Local Government is situated in the southern part of Taraba state. It is bordered to the north by Ibi Local Government Area, east by Gassol Local Government Area, from the south by Donga Local Government Area of Taraba State, and to the west by Ukum Local Government Area of Benue State. The Local Government Area has a total area of 4,308km^2 (1,663 square mile), located at 7°51′N 9°47′E. According to 2006 National population Census figures, Wukari has a population of 241,546 people (NPC, 2006).

b) Nature and Sources of Data

The study employed the use of secondary data in its analysis of the effects of climate change on maize yield in the study area. Climate data constituting of annual rainfall and temperature for Wukari Local Government Area of Taraba State for a period of twenty years (from 1999-2018) was obtained from the Nigeria Metrological Agency (NIMET) on a yearly basis, while data on the selected crop yield under study Maize) was obtained from Agriculture Development Program (ADP) Headquarters, Jalingo, Taraba State.

c) Methods of Data Analysis

The data for this study were processed and analysed quantitatively. The quantitative data were analysed using both descriptive and inferential statistics with the help of Microsoft Excel and the E-Views 10 statistical package. The descriptive statistics employed in the study was the time series trend analysis, while the

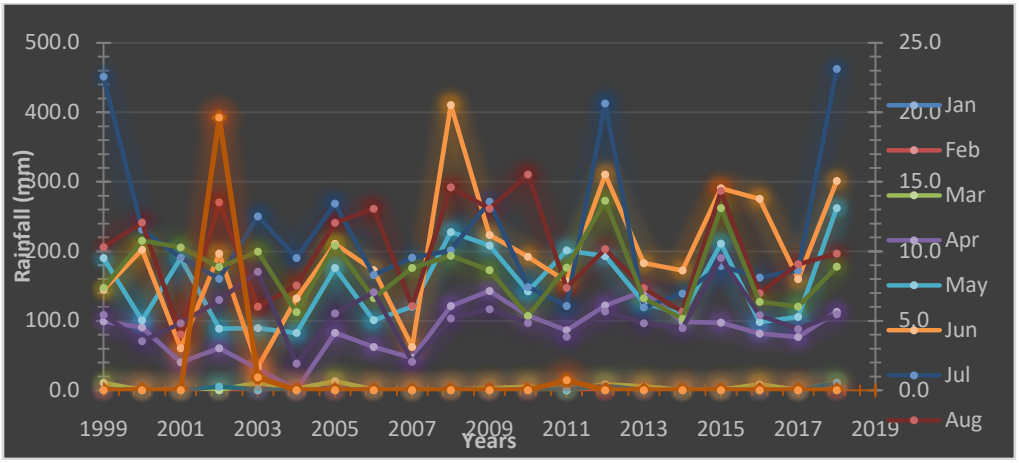
inferential statistics employed in the study was the Ordinary Least Square (OLS) regression, and correlation analysis to determine the effect of rainfall and temperature variability on maize (*Zea mays*) yield in the study area, as well as the relationship that exist between these variables under study.

III. Results and Discussion

a) The Trend of Rainfall and Temperature in the Study Area

Discussed below are the results of objective one, which deals with the trend of rainfall and temperature in the study area.

b) Trend of Rainfall



Source: Author's computation, 2019.

Figure 1: Trend Chart of Monthly Rainfall Distribution in the Study Area

Table 1: Monthly and Average M*onthly Rainfall Distribution in the Study Area (mm)*

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	0.0	0.0	10.2	98.6	189.8	144.4	451.1	205.5	147.0	108.0	0.0	0.0
2000	0.0	0.0	0.0	90.2	100.2	202.0	231.0	240.9	215.0	70.2	0.5	0.0
2001	0.0	0.0	0.0	40.0	190.0	60.1	190.6	80.0	205.3	96.1	0.0	0.0
2002	0.0	0.0	0.0	60.3	88.4	196.2	160.2	270.0	176.9	129.6	5.0	19.6
2003	0.0	0.0	10.5	30.6	89.0	33.1	250.0	120.0	199.1	170.4	0.9	0.9
2004	0.0	0.0	2.0	0.4	82.1	132.1	190.2	150.3	112.0	38.1	0.0	0.0
2005	0.0	0.0	12.6	82.4	175.6	210.2	268.2	240.6	208.0	110.1	0.0	0.0
2006	0.0	0.0	0.8	62.1	100.5	172.5	165.6	260.8	132.6	140.6	0.8	0.0
2007	0.0	0.0	0.0	46.2	120.0	62.1	190.4	120.8	175.6	40.7	0.0	0.0
2008	0.0	0.0	0.9	121.0	227.5	410.2	201.0	291.8	193.2	102.8	1.8	0.0
2009	0.0	0.0	2.2	142.6	208.1	223.3	271.0	261.0	172.5	116.4	0.0	0.0
2010	0.0	0.0	5.0	107.2	142.0	191.7	148.2	310.3	106.6	96.5	0.8	0.0
2011	0.0	0.0	0.0	86.0	201.0	156.0	121.1	147.0	176.1	76.9	0.9	0.7
2012	0.0	0.0	8.2	121.6	192.6	310.0	412.6	202.8	272.5	113.1	6.0	0.0
2013	0.0	0.8	5.2	142.1	126.0	182.7	119.1	146.6	132.1	96.2	0.0	0.0
2014	0.0	0.0	0.0	98.1	108.4	172.1	139.0	112.8	102.7	89.0	0.0	0.0
2015	0.0	0.0	0.5	96.8	210.9	290.2	178.6	286.5	262.0	189.8	0.5	0.0
2016	0.0	5.0	8.2	81.5	97.7	275.0	162.1	139.5	127.0	107.5	0.0	0.0
2017	0.0	0.0	0.0	76.1	105.2	159.8	172.2	181.0	120.0	87.9	0.0	0.0
2018	0.0	0.8	10.2	112.7	262.0	301.0	462.2	196.5	177.4	109.1	10.1	0.0
Average Monthly Rainfall	**0.0**	**0.3**	**3.8**	**84.8**	**150.9**	**194.2**	**224.2**	**198.2**	**170.7**	**104.5**	**1.4**	**1.1**

Source: Nigeria Meteorological Agency (NIMET), Taraba State, 2019.

The data presented in Table 1 depicts the distribution of rainfall in the study area over a spread of twenty years on a monthly basis. The data also shows the average monthly rainfall distribution in the study area as well. The data presented in the table is a true representation of the pattern of rainfall in Wukari Local Government Area of Taraba State and thus shows the level of variability of rainfall in the study area as a result

of the impact of climate change over the years. Looking at the results presented in the table, it can be observed that the month of January over the past twenty years has never experienced rainfall in the study area. While other part of Nigeria does experience what is considered unlikely rainfall during this month, Wukari Local Government Area is an exception, usually because it is located at the North-east part of the country, and because the month of January is considered the peak period of harmattan/dry season.

Beside the month of January that did not experience rainfall in the study area, the months of February through December recorded rainfall in the study area at a fluctuating rate. However, it is important to note that the months of February, December, November and March recorded the lowest drop of rainfall in the study area across the entire time frame under consideration. As depicted in the table, the month of February experienced rainfall only in the year 2013 and 2018, recording an average rainfall of 0.3mm, while the month of December experienced rainfall in the year 2002, 2003, and the year 2011, recording an average rainfall of 1.1mm during these periods. In the same vein, the study area experienced rainfall in the month of November in the year 2000, 2002, 2003, 2006, 2008, 2010, 2011, 2012, 2015, and the year 2018, recording an average rainfall of 1.4mm across these years. Unlike the month of February, December and November, the month of March in the study area experience more frequent rainfall over the time frame under consideration. it is however important to state that the frequent rainfall experienced during this month was less significant, as an average rainfall of only 3.8mm was recorded for across the entire years under consideration. The trend chart depicted in Figure 1 depicts and provides a vivid e picture of the nature of rainfall variability on a monthly basis in the study area across the entire years under consideration in the study. From the trend chart, it can be observed that the peak periods of rainfall in the study area occurs in the months of June, July, August, and the month of September respectively. From the data presented in Table 1, it can be observed that the month of June recorded an average rainfall of 194.2mm, while the month of July recorded an average rainfall of 224.2mm. Furthermore, the month of August and September recorded and average rainfall of 198.2mm and 170.7mm respectively. It however important to explicitly state that the month of July is the most peak period of rainfall in Wukari Local Government Area of Taraba State.

From the scattered plot in the trend chart, it can be observed that highest drop of rainfall in a singular month was experience on the month on July, in the 1999 and 2018 respectively. During these periods, total rainfall for the month in question was recorded at 451.1mm (in the year 1999) and rainfall was recorded at 462.2mm (in the year 2018) respectively. Close to these figures for total rainfall for a singular month, is the month of June, 2008. During this period, rainfall was recorded at 410.2mm. For non-peak periods of rainfall, on the month of December recorded significant rainfall for a singular month, at 19.6mm in the year 2002.

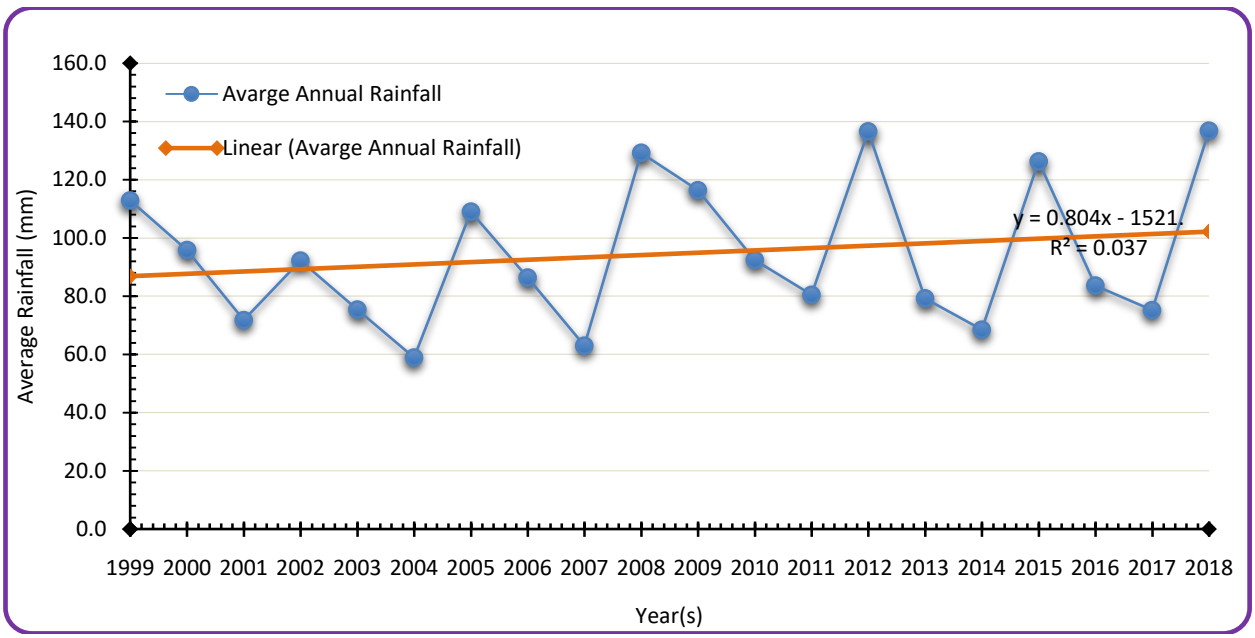
Table 2: Total and Average Annual Rainfall Distribution in the Study Area

S/N	Years	Total Annual Rainfall (mm)	Average Annual Rainfall (mm)
1	1999	1354.6	112.9
2	2000	1150.0	95.8
3	2001	862.1	71.8
4	2002	1106.2	92.2
5	2003	904.5	75.4
6	2004	707.2	58.9
7	2005	1307.7	109.0
8	2006	1036.3	86.4
9	2007	755.8	63.0
10	2008	1550.2	129.2
11	2009	1397.1	116.4
12	2010	1108.3	92.4
13	2011	965.7	80.5
14	2012	1639.4	136.6
15	2013	950.8	79.2
16	2014	822.1	68.5
17	2015	1515.8	126.3
18	2016	1003.5	83.6
19	2017	902.2	75.2
20	2018	1642.0	136.8
	Total	22681.5	1890.1

Source: Nigeria Meteorological Agency (NIMET), Taraba State, 2019.

Table 2 gives a detailed account of the rainfall trend rainfall variability in Wukari Local Government Area of Taraba State. Depicted in Figure 2, the trend plot in the chart shows a fluctuating trend mean rainfall in the study area. From the trend chart, it can be observed that from the period of 1999 to 2001 recorded decreasing trends in average rainfall at 112.9mm for the year 1999, 95.8mm for the year 2000, and 71.8mm for the year 2001. The year 2002 experienced a slight increase in the average annual rainfall in the study area, recorded at 92.2mm. In the year 2003 and 2004, a decrease in the average annual rainfall was experienced. Within these two years, average annual rainfall was recorded at; 75.4mm, and 58.9mm respectively.

From the trend chart, it can be observed that a significant increase in average annual rainfall in the year 2005 coursed and upward shift in the trend plot, as the average annual rainfall for this year was recorded at 109.0mm.This increase was however temporal as a decline in average annual rainfall was experienced in the year 2006 and 2007. During these years, average annual rainfall was recorded at 86.4mm and 63.0mm respectively.



Source: Author's computation, 2019.

Figure 2: Trend Chart of Annual Average Rainfall

While the improvement in average annual rainfall was experienced in the year 2008 and 2009, it is important to note that this improvement can be said to be a remarkable increase compared to the preceding three years, as the average annual rainfall recorded these were; 129.2mm and 116.4mm.The year 2010 and 2011 recorded a steady decline in the average annual rainfall of the study area. This decline is made vivid, as depicted by the downward slope of trend plot in the figure above. During these periods, the following the following amount of average annual rainfall was recorded; 92.4mm, and 80.5mmrespectively. A look at the trend plot shows that an upward movement occurred in the year 2012. This upward movement by interpretation signify an increase in the average annual rainfall in the year concerned. The year 2013 and 2014 recorded a significant decline in the average annual rainfall of the study area. This decline is made vivid by significant downward shift in the trend plot presented in the figure above. In this years, average annual rainfall was recorded at 79.2mm and 68.5mm. It

Compared to preceding year (2013 and 2014), the year2015recorded an increase in average annual rainfall at; 126.3mm, while the year 2016 and 2017 experienced a decrease in average annual rainfall at 83.6mm and 75.2mm. Worthy of note here is that that the year 2018 recorded the highest average annual rainfall in Wukari Local Government Area of Taraba State across the period of 1999 to 2018, recording rainfall of 136.8mm. The value of r^2 in the trend equation indicates a variation in trend of annual rainfall at 37 percent.

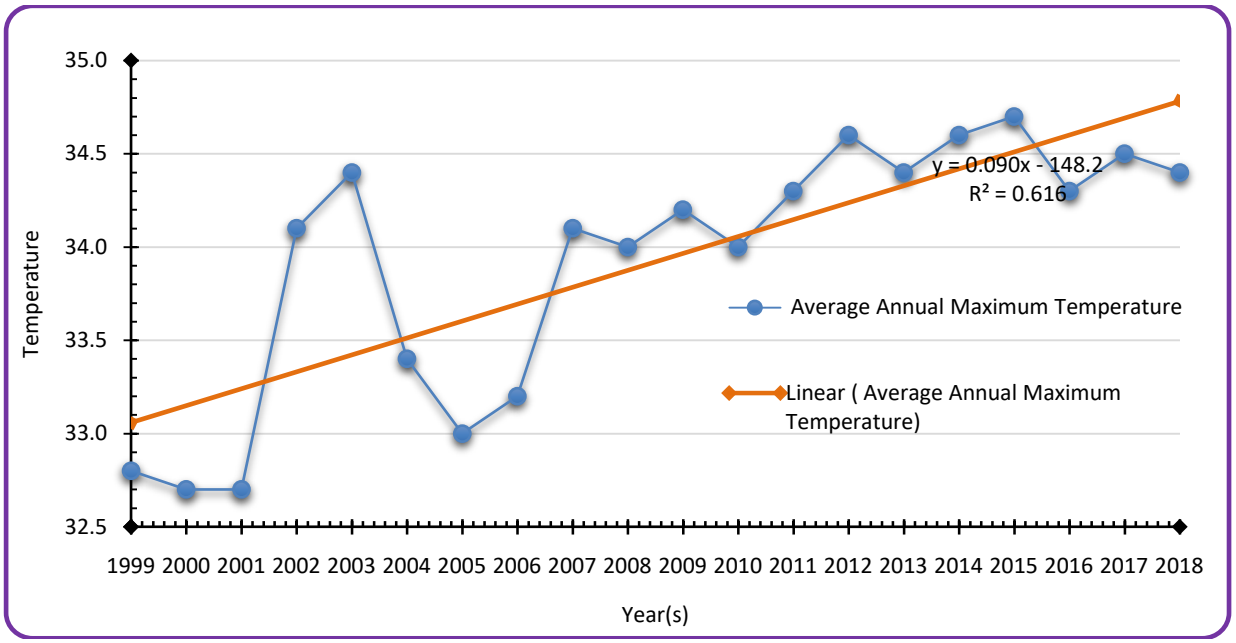
c) *Trend of Temperature in the Study Area*

Table 3: Temperature Distribution in the Study Area

S/N	Year	Total Max. Temperature (°c)	Average Max. Temperature (°c)	Total Min. Temperature (°c)	average min. temperature (°c)	Average Temperature (°c)
1	1999	393.4	32.8	261.8	21.8	27.3
2	2000	392.9	32.7	260.1	21.7	27.2
3	2001	392.3	32.7	259.0	21.6	27.15
4	2002	408.7	34.1	261.6	21.8	27.95
5	2003	413.3	34.4	272.3	22.7	28.55
6	2004	400.3	33.4	266.8	22.2	27.8
7	2005	396.2	33.0	266.0	22.2	27.6
8	2006	398.8	33.2	272.2	22.7	28.0
9	2007	408.9	34.1	264.8	22.1	28.1
10	2008	407.7	34.0	272.5	22.7	28.4
11	2009	410.7	34.2	256.6	21.4	27.8
12	2010	408.5	34.0	258.6	21.6	27.8
13	2011	411.4	34.3	263.1	21.9	28.1
14	2012	415.7	34.6	258.9	21.6	28.1
15	2013	413.1	34.4	255.5	21.3	27.9
16	2014	414.9	34.6	264.6	22.1	28.4
17	2015	416.5	34.7	264.8	22.1	28.4
18	2016	411.4	34.3	259.1	21.6	28.0
19	2017	413.7	34.5	258.7	21.6	28.1
20	2018	413.1	34.4	264.0	22.0	28.2

Source: Nigeria Meteorological Agency (NIMET), Taraba State, 2019.

d) *The Trend of Average Annual Maximum Temperature in the Study Area*



Source: Author's computation, 2019.

Figure 3: Trend Chart of Average Annual Maximum Temperature

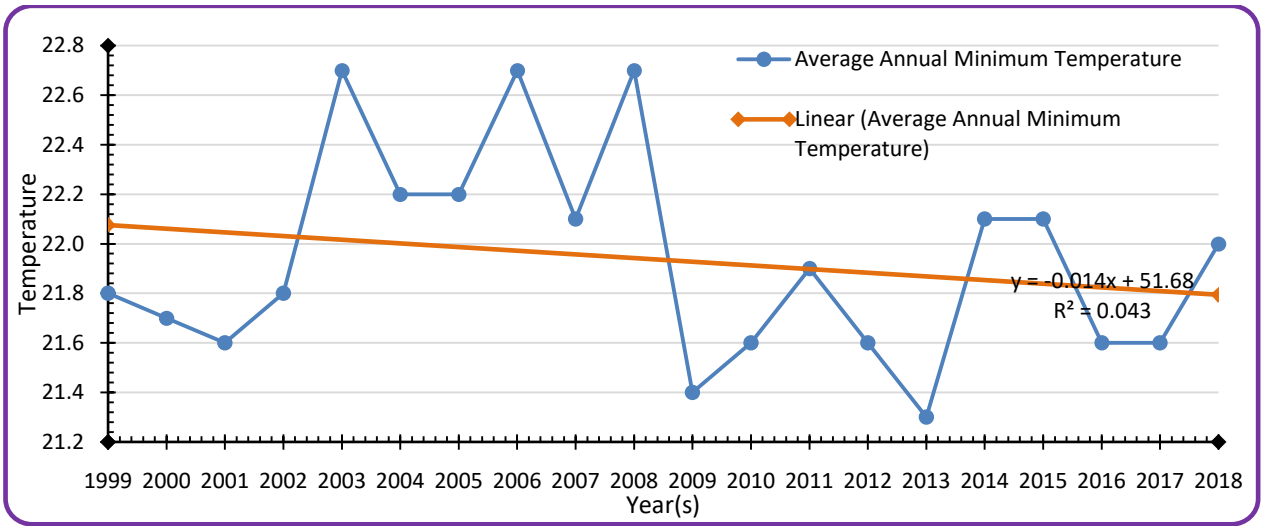
The scatter plot depicted in Figure 3 represents Average annual maximum temperature trend in the study area across the period under consideration. From the chart, it can be observed that the trend plot is upward sloping in nature. The upward sloping plot of the linear trend line indicates an increasing trend in average annual maximum temperature in the area of study over the time frame under consideration. If we critically observe the trend plot from the period of 1999 to 2001, it will be noted that there was a steady decline in the average annual maximum temperature within these periods. In 1999, the average annual maximum temperature was recorded at 32.8°c. In 2000, average annual maximum temperature recorded a slight increase compared to the preceding year, at 32.7°c. While the year 2001 experienced the same average annual maximum temperature as that of the year 2000 at 32.7°c. Compared to the year 1999-2001, the year 2002 and 2003 recorded a significant increase in the average annual maximum temperature in the study area, as depicted by the sharp upward movement of the trend plot chart. The increase the average annual maximum temperature was indeed significant, as temperature of 34.1°C and 34.4°C was experienced.

The sharp decline in the average annual maximum temperature experienced in the study area in the year 2004 and 2005 as depicted by the sharp downward slope of the trend plot. This sharp decline in average annual maximum temperature was however immediately accompanied by a gradual and steady increase in the average maximum temperature between the periods of 2006 to 2009 as depicted by the upward movement in the trend plot. Within these years the following average annual maximum temperature figures were recorded; 33.2°c, 34.1°c, 34.0°c, and 34.2°c respectively. While the average annual maximum trend in temperature in the study area was steadier and increasing during the periods discussed above (i.e. from 2006 to 2009), the year 2009 experienced a slight decline in average maximum temperature at 34.0°c. The year 2011-2015 however experience a much increasing but fluctuating trend in the average annual maximum temperature in the study area at; 34.3°c, 34.6°c, 34.4°cc, 34.6°c, and 34.7°c respectively. However, the year 2016-2018 experienced a fluctuating decline in the average annual maximum temperature, at 34.3°c, 34.5°c and 34.4°c respectively.

Generally, the degree of variation in increase or decrease in a trend analysis is determined by the nature of the trend line. The degree of reliability of a trend line is determined by the nature of its R-square value. A trend line is said to be most reliable when its r-square value is at or near one (1). There are many types of trend line that can be employed in a trend analysis. However, for the purpose of this research, the researcher employed the linear trend line, because it is the best-fit straight line that can be used with a simple linear data set. The upward sloping nature of the linear trend line in the figure above thus implies a steady increase in Average maximum temperature in the study area over a 21-year period. Notice that that the r-square value is 0.6163. This value is not 1, as such cannot be said to be a good fit of the line to the data. The value however implies that the degree of increase in the average annual maximum temperature in the study area over a 21-year period is 62 percent.

e) The Trend of Average Annual Minimum Temperature in the Study Area

Figure 4 depicts the trend of average annual minimum temperature in Wukari Local Government Area of Taraba State. A careful look shows at the trend plot shows a decreasing trend in the average annual minimum temperature in the area of study over the time frame under study. A gradual and steady decrease in average minimum temperature was recorded within the periods of 1999 to 2001 at 21.8°c, 21.7°c, and 21.6°crespectively. However, the year 2003 experienced a significant rise in the average temperature of the study area as depicted by the upward movement of the trend chart. During this period, the average temperature recorded was 22.7°c. From the trend chart, it can be observed that a decline in average temperature was experienced in the study area in the year 2004 and 2005, compared to the year 2003. More so, a constant level of average temperature was recorded (in the year 2004 and 2005). During these periods, the average temperature of the study area was 22.2°c respectively.



Source: Author's computation, 2019.

Figure 4: Trend Chart of Average Annual Minimum Temperature

The year 2006 experienced an increase in the average temperature in the study area at 22.7°c, compared to the years 2004 and 2005. However, this increase was a one-off, as the year 2007 experienced a decline in average temperature. The average temperature recorded during this period (2007) was 22.1°c. More so, the year 2008 experienced an increase in the average temperature in the study area at 22.7°c. From the trend chart, it can be observed that there is steep downward slop in the trend plot. This steep downward slope indicates a significant drop in the average temperature of the study area in the year concerned, which in this case was the year 2009. During this period, the average temperature of the study area was 21.4°c. Given this significant decline in the average temperature in the study area, the year 2010 and 2011 experienced a steady increase in average temperature in the study area at 21.6°c and 21.9°c respectively. In the same vein, the movement of the trend chart depicts a decline in average temperature of the study area in the year 2012 and 2013 respectively. During these periods, the average temperatures recorded were 21.6°c and 21.3°c.

Compared to the year 2012 and 2013, the year 2014 and 2015 recorded a steady increase in average temperature in the study area. More so, this increase was at a constant digit for both years. Explicitly, the average temperature recorded was at 22.1°c respectively. A decline in average temperature was experienced in the year 2016 and 2017. More so, the decline was at a constant digit similar to the experience of the year 2012 and 2013, but at a different value (21.6°c), while the year 2018 experienced an increase in average temperature at 22.0°c.

It is important to point out here that the year 2013 recorded the least average temperature experienced in the study area between the year 1999 and 2018, at 21.3°c, while the highest average temperature recorded in the study area across the time frame under study was 22.7°c, recorded in the year 2003, 2006, and 2008. More so, uniformity in the value of average temperature was experienced in the study. For instance, the year 2004 and 2005 recorded the same average temperature (22.2°c), 2003, 2006, and 2008 at 22.7°c, 2010 and 2012 at 21.6°c, 2014 and 2015 at 22.1°c, and the year 2016 and 2017 at 21.6°c. The value of r^2 in the trend equation shows the degree of variation in the average temperature in the study area. The value indicates a 44% decreasing trend in the average temperature of the study area between the year 1999 and 2018.

f) The Trend of Maize Yield in the Study Area

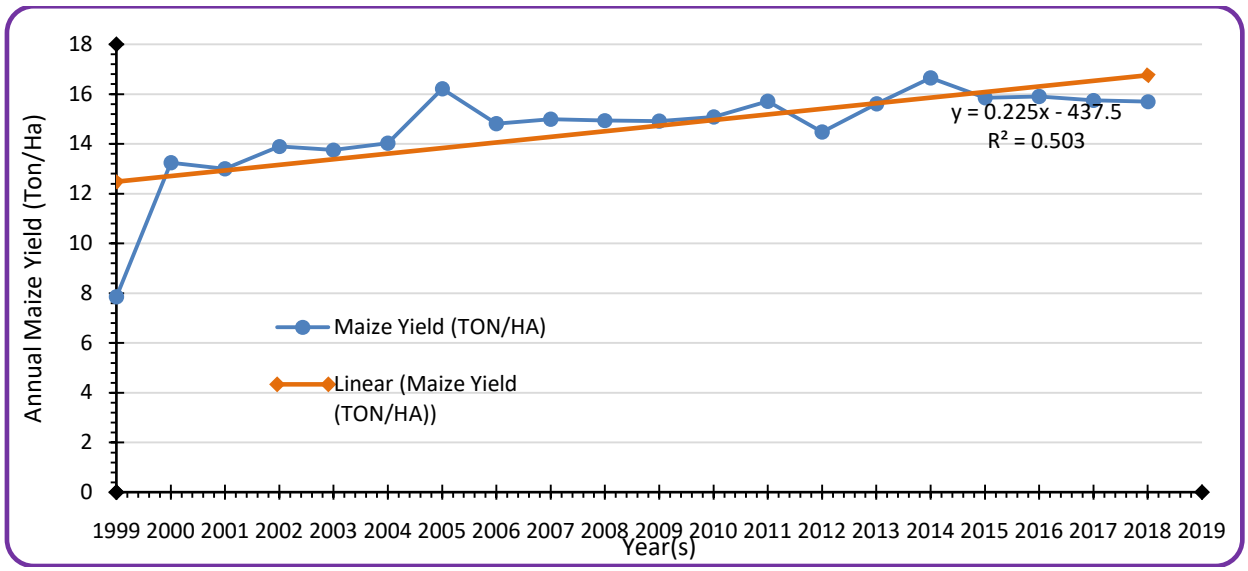
The results and analysis presented in this sub-section provided answers to the second research question raised, and satisfy the second objective of the study. The trend of maize yield between the periods 1999 to 2018 in the study area was generated from the data presented in the Table 4.3 and depicted in Figure 4.5. The trend presented in the chart above reveals an increasing trend in maize yield in the study area over the period under study, as depicted by the trend line. In year 2000, a sharp increase in yield was experience, as 13.24t/ha was recorded. A slight decrease in yield was experienced in the year 2001, as 12.99t/ha of maize was recorded. This decrease in yield was however, only temporal, as the year 2002-2017 experienced increase in yield, compared to the years that precede them. Although variations in terms of increases and decrease in yield were experienced, it is important to note that these decreases cannot be classified as a significant decrease in yield.

Between the year 2002 to the years 2005, a steady increase in yield was experienced at 13.9t/ha, 13.76t/ha, 14.02t/ha and 16.21t/ha respectively. Worthy of note here is the fact that the year 2005 recorded the highest yield in maize in the study area overt entire period under consideration in this study. Compared to the year 2005, the period of 2006 to 2009 recorded a decrease in maize yield, as 14.18t/ha, 14.99t/ha, 14.94t/ha and 14.91t/ha were recorded respectively.

Table 4: Maize yield Output in Wukari Local Government Area of Taraba State

S/N	Years	Maize Yield (TON/HA)
1	1999	7.85
2	2000	13.24
3	2001	12.99
4	2002	13.90
5	2003	13.76
6	2004	14.02
7	2005	16.21
8	2006	14.81
9	2007	14.99
10	2008	14.94
11	2009	14.91
12	2010	15.08
13	2011	15.71
14	2012	14.47
15	2013	15.60
16	2014	16.65
17	2015	15.85
18	2016	15.90
19	2017	15.75
20	2018	15.70
Total		308.16

Source: Taraba A.D.P HQRS, Jalingo, Taraba State, 2019.



Source: Author's computation, 2019.

Fig. 5: Trend of Maize Yield

In 2010 and 2011, 15.08t/ha and 15.71t/ha yield was recorded, representing an increase as compared to the 2006 to the year 2009. While, in the year 2012, a decrease in yield was recorded at 14.47t/ha. A steady increase was experienced from the period of 2013 to 2017 at; 15.6t/ha, 16.65t/ha, 15.85t/ha, 15.9t/ha and 15.75t/ha respectively. Thus, it should be noted the year 2005 recorded the highest amount of maize yield at 16.21t/ha in the study area, between the period of 1999 to 2018. The trend equation indicates a variation in maize yield in the study area over the period under consideration at 50 percent as indicated by the value of r^2. This by implication simply implies that there is a significant variation in the trend of maize yield in the study area over the period under consideration.

g) Relationship between Rainfall, Temperature, and Maize yield, in the Study Area

Presented and analysed below are results that satisfy the third objective of the study, and answers the third research question raised in chapter one.

Table 5: Correlation between Rainfall, Temperature, and Maize Yield in the Study Area

		Average Rainfall (mm)	Average Temperature (°c)	Maize Yield (TON/HA)
Average Rainfall (mm)	Pearson Correlation	1	0.088	-0.072
	Sig. (2-tailed)		0.712	0.762
	N	20	20	20
Average Temperature (°c)	Pearson Correlation	0.088	1	0.564**
	Sig. (2-tailed)	0.712		0.010
	N	20	20	20
Maize Yield (TON/HA)	Pearson Correlation	-0.072	0.564**	1
	Sig. (2-tailed)	0.762	0.010	
	N	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Source: IBM SPSS version 26 Pearson Product Moment Correlation analysis result, 2019.

The relation between rainfall, temperature, and maize was examined through the Pearson Product Moment Correlation and a two-tail test employed. The result extract presented in Table 5, shows the correlation coefficient between average rainfall and average temperature at 0.088. This by interpretation indicates a strong positive linear correlation (relationship) between the average rainfall and average temperature in the study area between 1999 and 2018. The significant value (2-tailed test) of the correlation coefficient between average rainfall and average temperature was 0.712. This thus implies that though there is a strong positive linear correlation (relationship) between rainfall and temperature in the study area between 1999 and 2018, this relationship was not statistically significant (since $0.712 > 0.05$).

The result extract also revealed the correlation coefficient between rainfall variability and maize yield in the study area at -0.072. This coefficient by interpretation implies a weak negative correlation (relationship) between average rainfall variability and maize yield in the study area between 1999 and 2018. The significant value (2-tailed test) of the correlation coefficient between average rainfall variability and maize yield was 0.762. This by implication, implies that the weak negative linear correlation between average rainfall and maize yield in the study area was not statistically significant (since $0.762 > 0.05$). Hence, the null hypothesis which posited that there a significant relationship between relationship between rainfall variability and maize yield in the study area was rejected. The correlation analysis revealed the correlation coefficient between average temperature variability and maize yield in the study area between 1999 and 2018 at 0.564. This correlation coefficient by interpretation implies a moderate positive linear correlation (relationship) between average temperature and maize yield in the study area over the time frame under study. The significant value (2-tailed test) of the correlation coefficient between average temperature and maize yield was 0.010. This by implication, implies that the moderate positive linear correlation between average temperature variability and maize yield in the study area was statistically significant (since $0.010 < 0.05$). Hence, the null hypothesis which posited that there a significant relationship between relationship between temperature variability and maize yield in the study area was accepted.

h) Effects of Rainfall and Temperature Variability on Maize Yield in the Study Area

The results presented and analysed in this subsection satisfy the fourth objective of the study, and answered the fourth research question raised earlier (see chapter one).In order to evaluate the effects of rainfall and temperature variability on maize yield in

Wukari Local Government Area of Taraba State, a linear regression analysis was carried out. Regression analysis by definition is a set of statistical processes for estimating the relationships among variables. A regression analysis was employed because it helps one understand how the typical value of the dependent variable (or criterion variable) changes when any one of the independent variables is varied, while the other independent variables are held constant. The results presented in Table 4.6a revealed the regression coefficients the variables of the study, while Table 4.6b revealed the summary results of the regression model.

Table 4.6: Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Std. Error of the Estimate
	B	Std. Error	Beta			
Constant	-61.140	26.435		-2.313	0.034	1.62138
Average Rainfall	-0.009	0.015	-0.123	-0.618	0.544	
Average Temperature	2.743	0.949	0.575	2.890	0.010	

Source: IBM SPSS version 26 linear regression analysis, 2019.

Juxtaposing the above result extract into the linear regression model postulated in chapter three of the study, we have;

$$mY = \alpha + \beta_1 Rf + \beta_2 T + e = \text{regression equation}$$

$$\text{mY} = -61.140 + (-0.009) + 2.743 + 1.62138$$

From the results of the regression coefficient, it can be observed that the constant parameter α is negatively related to Maize yield in the study area across the time frame under study, with a *t*-value of -2.313. The *p*-value of the constant parameter of 0.034 implies a statistically significant negative relationship ($0.034 < 0.05$) between the constant parameter and the dependent variable of the study. The coefficient of $\beta_1 Rf$ (average rainfall) revealed a negative relationship between rainfall and maize yield in the study area, with a coefficient value of -0.009. The *t*-value of the coefficient of $\beta_1 Rf$ (average rainfall) was -0.618, with a *p*-value of 0.544. This thus implies that the negative relationship between the dependent variable (maize yield) and average rainfall in the study area was not statistically significant ($0.544 > 0.05$). The coefficient of the β_1 does not conform to the theoretical aprior expectation of posited that $\beta_1 > 0$.

The results also revealed the regression coefficient of average temperature in the study area. From the results, the coefficient of $\beta_2 T$ (average temperature) was 2.743. This coefficient implies a positive relationship between maize yield and average temperature in the study aera across the time frame under study. The *t*-value of coefficient of $\beta_2 T$ (average temperature) was 2.890, with a *p*-value of 0.010. This by implication implies that the positive relationship between maize yield and average temperature in the study area was statistically significant ($0.010 < 0.05$).More so the coefficient of β_2 conforms to the theoretical aprior expectation that $\beta_2 > 0$.

Table 4.7: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig	Durbin-Watson
1	0.577[a]	0.333	0.254	1.62138	4.243	0.032[b]	1.412

a. Predictors: (Constant), Average Temperature (°c), Average Rainfall (mm)
b. Dependent Variable: Maize Yield (TON/HA)

Source: IBM SPSS version 26 linear regression analysis, 2020.

The result extract in Table 4.7 presents the model summary of the linear regression analysis of the study. From the results, the correlation of result (R = 0.577) indicates a strong positive linear relationship between the dependent variable and the independent variables in the regression model. The results further depict the effect of variation rainfall and temperature on maize yield in the area of study with value of the coefficient of determination, also known as the r^2, as well as the coefficient of the adjusted coefficient of determination, also known as the adjusted r-square $\bar{R}^2$. The coefficient of determination (r-square: r^2) by definition, is the proportion of the variance in the dependent variable (Maize yield in this case), that is predictable from the independent variable(s) (rainfall, and temperature), was arrived at 0.333.This thus implies that 33 percent of the variation in maize yield is explained by the variation in rainfall, and temperature between the periods of 1999 and 2018 in Wukari Local Government Area of Taraba State.

The use of the adjusted r-squareis an attempt to take account of the phenomenon of the r-square automatically and spuriously increases when extra explanatory variables are added to the model. It is a

modification due to Henri Theil (1961) r-square of that adjusts for the number of explanatory terms in a model relative to the number of data points. The adjusted r-square can be negative, and its value will always be less than or equal to that of r-square. Unlike r-square, the adjusted r-square increases only when the increase in r-square (due to the inclusion of a new explanatory variable) is more than one would expect to see by chance.

In other words, the adjusted coefficient of determination ($\bar{R}^2$) is taken into consideration when the degree of freedom increases or decrease. This is to correct the defect of the inclusion of additional explanatory variables in the initial function. From the result extract of the regression analysis, the $\bar{R}^2$ was arrived at 0.254. This by implication implies that over 25 percent of the total variation in maize yield is explained by the variation in the explanatory variable (rainfall, and temperature) after taking into consideration.

The standard error of the regression estimate was 1.62138, while the Durbin-Watson test of 1.412 indicates the presence of positive autocorrelation in the regression. The F-statistic value of 4.243 shows the overall estimated regression model was at the conventional significance level of 0.05 level of significance, and found to be statistically significant. This was as a result of the F-statistics (4.243) found to be greater than the critical F-statistics significance of 0.032, which is less than 0.05 ($0.032 < 0.05$) at 5 percent level of significance. Hence, the research hypothesis which posited that rainfall and temperature variability have a significant effect on maize yield in the study area was accepted.

IV. Conclusion

In conclusion, rainfall and temperature affect maize yield in Wukari Local Government Area of Taraba State. Maize yield soars at minimal ambient temperature than at high temperature, that is, maize yield is linearly associated with minimal and average atmospheric temperature. Intriguingly, maize yield was inversely associated with maximum atmospheric temperature. That is, diminishing returns sets in at maximum temperature while optimal yield occurs at minimum temperature. Regarding rainfall, maize yield was inversely associated with rainfall. For optimal maize yield, low (minimal) temperature and low rainfall are *sine qua non*. Equations of line of best fit and trend line are extrapolated for each graph. Linear regression equation was used to generate predictive equations for estimating maize yield using temperature, rainfall and their composite.

Crops are vulnerable to the effects of climatic variations and this precipitates poor yields. Besides the fact that the crop yields are climate reliant, other variables such as farm administration systems, seed type, soil fertility, pest and planting period may contribute fundamentally to varieties in crop yield. This study will appreciate the recommendations outlined in this work to be disseminated to redress the depleting crop yield experienced by the farmers in Wukari Local Government Area for a sustainable future. Subsequently, for future study, specific technologies and administration styles may need to be developed to ensure the sustainability of agricultural products.

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Certificate, LoR and Momento **2** discounted publishing/year **Gradation** of Research **10** research contacts/day **1 GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day **5 GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

Preferred Author Guidelines

We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

Before and during Submission

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

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Plagiarism is not acceptable in Global Journals submissions at all.

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Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
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- Findings
- Writings
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- Printed material
- Graphic representations
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2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

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Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

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Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
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Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
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References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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