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Full Length Research Paper

Challenges and opportunities for implementation of Integrated Water Resource Management in Omo-Gibe Basin, Ethiopia

Yericho Berhanu Meshesha[1*] and Mulugeta Bekele Abdi[2]

[1]Department of Natural Resource Management, Bonga University P. O. Box 334, Bonga, Ethiopia.
[2]School of Natural Resource and Environmental Study, Wondo Genet College of Forestry and Natural Resources, Hawassa University, P. O. Box 128, Shashemene, Ethiopia.

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Water is an essential element for the environment, food security and sustainable development. However, uncoordinated and competitive use of the resource can lead water to face the "tragedy of the commons". Fragmented effects done so far in watershed management did not bring significant changes. Integrated water resource management is the ideal solution for sustainable development of the basins. This paper is targeted at assessing the challenges and opportunities of implementing integrated water resource management intervention in Omo-Gibe basin. The sample micro watersheds were strategically selected considering its accessibility for four-wheel vehicle and horse transportation. Five percent of the sample respondents were randomly selected for interview. Data were collected from all relevant sources through field observation, key informants interview, focused group discussion, household survey and review of documents. The collected data were analyzed by means of descriptive statistics including chi-square and t-test, using SPSS vision 20. The evidence in the basin shows that biophysical, socio economic and hydro political factors govern the implementation of integrated water resource management. Large proportion (65%) of steeply slope and land degradation, lack of understanding of IWRM principles and practices (72%), absence of river basin authority, no habit for planning together, lack of water resource infrastructure and innovation (81.9%), and weak local institutions commitment to transfer principles into practices were the major problems of the basin. In spite of having those limiting factors, the effort of the government through making policy on water resource management is a prospect for the basin, besides harmonious cultural interaction of the community to live together with nature and themselves. The Omo-Gibe River Basin has right to exist in harmony with its ecosystem to function sustainably. Human induced factors were limiting the wise use of scarce natural resources in the basin. Therefore, successful implementation of integrated water resource management though developing river basin authority, capacity building and enabling the environment is important for the basin, and for the country at large.

Key words: Basin authority, capacity building, enabling environment, river.

INTRODUCTION

Water is an essential element for the environment, food security and sustainable development (Cox, 1987). Rivers, lakes, swamps and wetland ecosystems have environmental value that contributes to human wellbeing and environmental sustainability (MEA, 2005). Most of these uses of water depend on the accessible fresh water resources, which constitute less than 1% of global water resources (Chander and Prasad, 2014).

Globally, fresh water resources are under high pressure due to socio economic and demographic reasons. The rise in demographic pressure, development activity and interest in competitive demand for water brought disputes over the limited fresh water resource. This situation is worsen by social inequity (male and female; developed and less developed), economic marginalization and poverty. Lack of technology and weak innovation lead to degradation of fresh water resource (GWP, 2000; Chander and Prasad, 2014; UNESCO, 2015). As the world population increases, demand for water rises and as climate changes add to the problems, there is a real threat of water scarcity in many parts of the world in general and in Ethiopia in particular. Due to natural and man-made reasons, millions of people, particularly in developing countries including Ethiopia, have limited or inadequate access to water. Lack of quality water as well as the availability of enough quantity is challenges to development in many areas of the world, especially in developing countries. This situation is worse in sub-Saharan countries. Hence, it affects the wealth and health of human beings. Moreover, water scarcity and water quality problems are of actual concern in African countries where many countries are less developed. In this region, there is often a connection between unavailability of good water resources and poverty (Chander and Prasad, 2014; UNESCO, 2015).

An attempt to solve the problems related to availability of water resource, management approach is required for its use and reuse. Through the history of water resource management, several management strategies were used. Top down approach, sectoral approach and integrated water resource management approaches are some of them. In top down water management approach, the central government is a service provider and is responsible for all water management in the country. This approach did not give due consideration for local community and professional participation, and it is not flexible. In sectoral water management approach, different sectors manage water resources differently. This approach lacks integration, cooperation and coordination. Weak management, systemic deficiencies of related institutions and governance, absence of a long-term vision, absence of consistent economic rationale for project selection, lack of community participation, heavily construction focused and inconsistent decision making characterize the previous water management approaches. Due to these draw backs, top down and sectoral water managements were left for integrated water resource management. IWRM approach has gotten great recognition by the International Conference on Water and Environment, Dublin 1992. The approach is participatory, involves users, planners and policy makers at all levels. Women play a central part and water is recognized as a social good and having economic value. *IWRM is a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.* The concept of Integrated Water Resources Management, in contrast to “traditional”, involves fragmented water resources management at its most fundamental level and is concerned with the management of water demand as with its supply (GWP, 2000).

Considering its relative advantages, Ethiopia has been implementing IWRM. The recent water resource management policy of the country relies on the principles of IWRM, which comprehend and integrate water uses for agriculture, energy, environment, navigation, drinking, sanitation, aquatic resources and industry (MoWR, 1999). Depending on the water resource management policy, strategies were designed to implement IWRM throughout the country since 2001 (MoWR, 2001). However, in spite of having its vital role in sustainable development, the implementation of IWRM has its challenges in water resource management at the river basin level. Due to its weak implementation of IWRM, the basin of the country has been facing problems such as flood damage, upstream and downstream conflicts and water use competition. The 2006 flood damage of Omo-Gibe River basin and Dire-dawa town are the indicators of ineffective implementation of IWRM. Moreover, uncoordinated and competitive use of the resource can lead water to face the “tragedy of the commons” (Yohannes, 2012). To solve such problems, integrated water resource management has great contribution. Hence, the role of effective implementation of IWRM into practice is indispensable. However, the experiences in the field show that there is miss match between the strategies of water resource management and the realities going on. Moreover, the practice of IWRM has not been implemented as its principles (Ibid). Lack of coordination among sectors and water user groups is evident. Moreover, overlaps in responsibilities in water resource management are also evidence of the lack of IWRM in the country. In fact, there is no scientific investigation

*Corresponding author. E-mail: yerichob@gmail.com.

conducted on this topic for local situations, even at the country level except the one conducted by Yohannis (2012) in Lake Tana basin. This also worsens the problem in Ethiopia in general as well as in Omo-Gibe basin in particular. Therefore, this study is designed to identify major challenges and opportunities regarding implementation of IWRM in Omo-Gibe basin in Ethiopia, and to provide base line information as well as the fact to make management strategies for successful implementation of IWRM.

Study area description

Ethiopia has twelve river basins: Abbay, Awash, Baro-Akobo, Genale-Dawa, Mereb, Omo-Gibe, Rift Valley, Tekeze, Wabe-Shebele, Afar-Denakil, Ogaden and Aysh with a total amount of 122 Billion Meter Cubic (BMC) annual runoff (Awulachew et al., 2007; Ayalew, 2018). The Omo-Gibe River basin is an important basin of Southern Ethiopia. Its course is entirely contained within the boundaries of Ethiopia, and empties into Lake Turkana on the border with Kenya. It is the principal stream of an endorheic drainage basin; the part that the Omo-Gibe River drains includes part of the Western Oromia Region and the middle of the Southern Nations, Nationalities, and People's Region (Figure 1).

The Omo-Gibe River basin has an area of 79,000 km^2, covering parts of the SNNPR and Oromia. The total mean annual flow from the river basin is estimated at about 17.9 BMC, that is, about 15% of the total runoff of the country. Large-scale and medium-scale irrigation potential is identified in the basin, with an estimated irrigable area of 57,900 and 10,028 ha, respectively, and a total irrigable area of 67,928 ha. In terms of hydropower development potential, it is the second largest and it is a basin in which most of the current hydropower development takes place. The basin is also endowed with a variety of wildlife, with Omo and Mago parks being located in the basin, its tourism potential will be further exploited as infrastructure develops in the area (Awulachew et al., 2007; Ayalew, 2018).

METHODOLOGY

For this study, Kaffa, Gurage, Hadiya, Wolaita and Dawuro zones as well as Yem-special district were strategically selected. The nearest district to Omo-Gibe River was selected from each zone, considering the availability of data and accessibility of the district for data collection using four wheel vehicle and horse. Following this step, two districts at most were selected from each zone. After this consideration, sample micro watersheds were randomly selected in the district. Moreover, 5% of sample respondents were randomly selected for interview from each sample micro watershed. Accordingly, about 248 heads of household interviews were conducted and sample size was constrained due to financial constraint. In addition, a total of eleven-focused group discussion was done (each comprising 6 to 12 participants). About 19 key informant's interviews were carried out. The key informants were elders and watershed development experts. The sample micro watershed, the number of group discussion and sample respondents were summarized in Table 1.

Before the formal data collection desk review was done, available archives in the local, regional and national offices were collected and reviewed. After that, permission was requested from respective local administrations to carry out the field activities, and then the fieldwork was done. Accordingly, formal and informal discussions with leader of the zones, districts, peasant association, institutions, and villagers were conducted. Based on the information obtained from the discussions, data collection process was employed through field observation, questionnaire survey, focused group discussion and key informants interview.

Field observation was focused on observation of biophysical characteristics of watershed like land degradation, crop patterns, distribution of settlements, individual activities in the farming plots, farmers' land management practices, water resources, bush and grazing lands, and other relevant aspects of water resource management in the catchment. The observation covered all sampled micro watershed in the districts. During the field observation, river course characteristics including water quality, availability, color and odor of water, water source protection systems or mechanisms, and ecological conditions were observed. Questionnaire survey was used to collect the primary data from sample households. The survey was conducted using both open and closed ended structured questions. It was focused on to get information on stakeholder's field practices as well as the strategies of water resource management sector. Focused group discussion was conducted based on checklists and semi-structured questionnaires prepared for this purpose. In this session, the information on resource use interactions, resource allocation systems, female participation in water resource management and related issues were raised and forwarded for analysis. Key Informant Interview was carried out with leaders and experts. Identification of key informants who have deep knowledge about the area was an essential task. They have deep-rooted experience and knowledge of their environment, which is vital to know details regarding water resource management in the area. They can also play significant role in leading local institutions as they were highly respected in the community. Thus, gaining their consent was an important step. Contacts with development agents, agricultural and water resource experts are also vital to assess the extent of water management in the area. Finally, the collected data was analyzed. Initially, editing and coding of the collected data was made. The process of examining the raw data in order to detect errors and omissions and to make correction if possible was done. After completion of editing, the process of assigning numerical symbols (coding) to the responses was done and then the collected data were entered into SPSS version 20. Descriptive statistics including t-test and chi-square test were used for analysis. Moreover, population figure was predicted through geometric growth method with 3% increment rate.

RESULTS AND DISCUSSION

Water resources of Omo-Gibe Basin and its uses

The Omo-Gibe River drains to the south from Ethiopia's humid highlands of Kaffa and West Shoa zones to arid lowlands, terminating in the Omo-Delta on Kenya's Lake Turkana through passing undulating gorges of Dawuro, Gurage, Wolaita and Hadiya zones (Figure 2). It is one of the most important water resource basins in Ethiopia and carries about 17.9 BMC mean annual flow, that is, 15% of

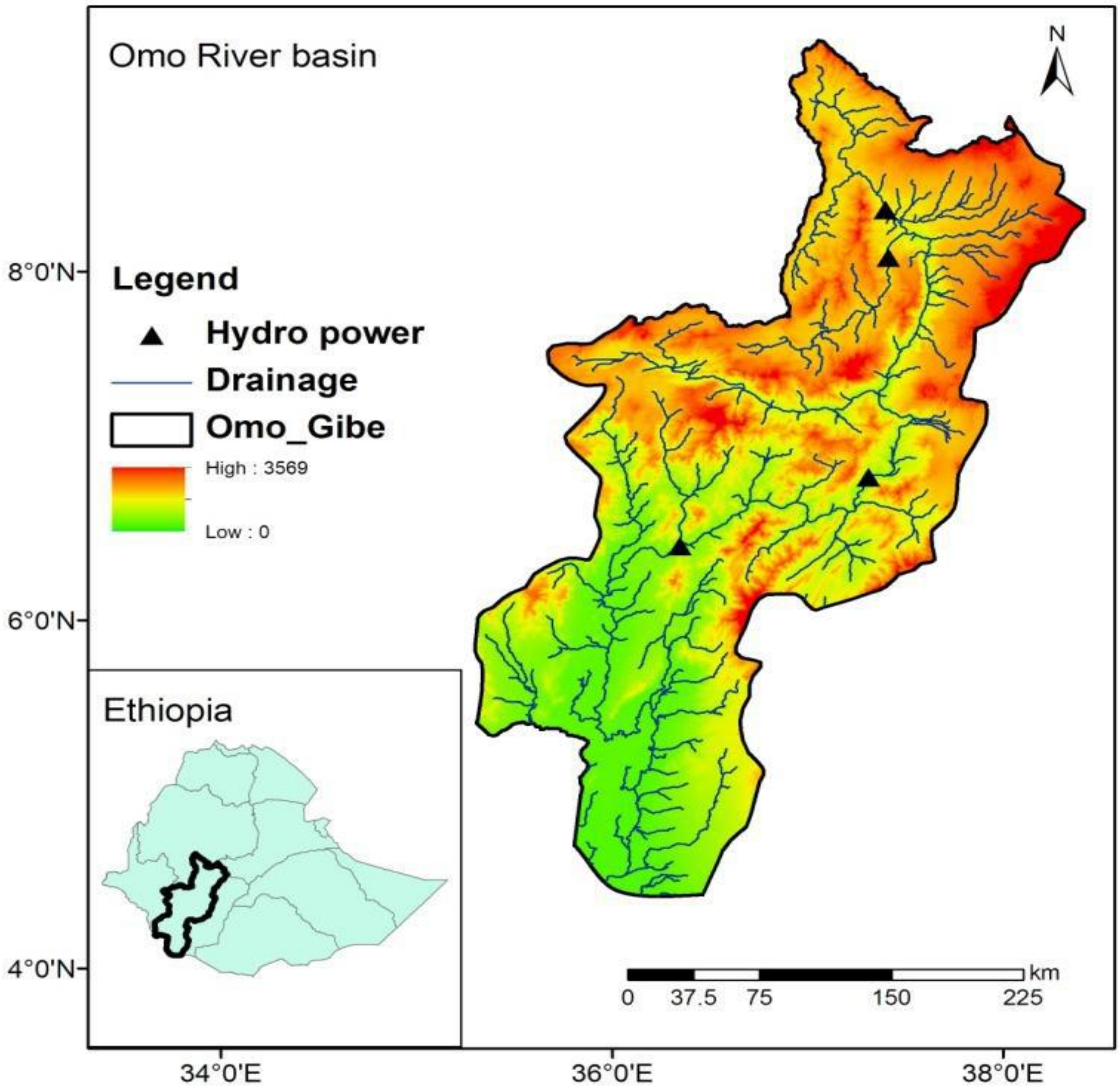

Figure 1. Omo-Gibe river basin.
Source: Eyasu et al. (2015).

Table 1. Selected sample micro watersheds and respondents distribution.

Zone/Special Woreda	District	Sample micro watershed	Sample respondents	Number of FGD	Key informants
Kaffa	Gimbo	Gojeb	20	1	2
	-	Dire Goma	17	1	1
Yem special	Yem Special	Fofa	27	1	3
Gurage	Abeshige	Gibe Genet	37	1	4
Hadiya	Gibe	Gibe	37	1	2
Wolaita	Kindo Koyisha	Belle	28	2	2
	Kindo Didaye	Gocce	27	1	2
Dawuro	Loma	Gessa	27	1	1
	Genna	Genna	28	2	2

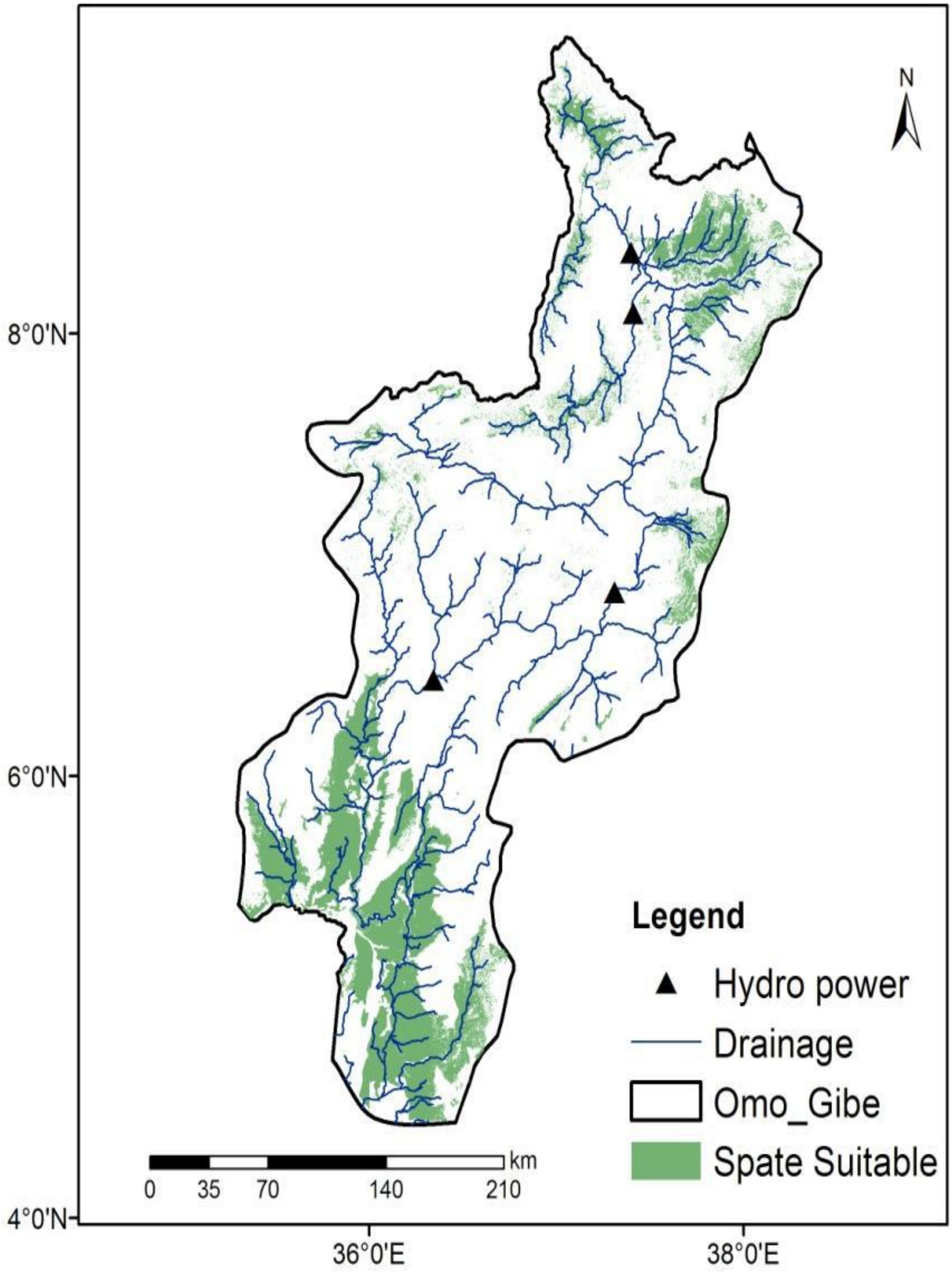

Figure 2. Drainage network of Omo Gibe basin.

the annual surface water resource of the country. The river provides about 90% of Lake Turkana's annual inflows and it sustains the ecology (Awulachew et al., 2007; Avery and Turton, 2012; Eyasu et al., 2015). The major water use interests in the area are water for Agricultural, Domestic, Hydropower and Recreation uses.

Table 2. Observed challenges in the basin.

Factor	Response		Percentage	
	Yes	No	Yes	No
Demographic pressure	248	0	100.0	0.0
Lack of understanding of IWRM principles and practices	179	69	72.2	27.8
Inadequate information and data management	151	97	60.9	39.1
Lack of basin authority	248	0	100.0	0.0
Environmental degradation	248	0	100.0	0.0
Gender disparities	155	93	62.5	37.5
Lack of water resource infrastructure and innovation	203	45	81.9	18.1
No habit for planning together	221	26	89.1	10.5
Weak in risk management	167	81	67.3	32.7
Weak institutional commitment to transfer principles in to practices	245	3	99	1

Agricultural water demand for irrigation is dominant in lower parts of the basin, unlike in the upper and middle parts. This is because of unsuitable undulating topography for irrigation development. The water use for irrigation is relatively fewer than other uses. Similarly, the previous studies showed that the irrigation potential of this basin is less than 10% of the catchment total area (Awulachew et al., 2007).

The water use for hydropower is well known in the basin since Gibe I, II and III are functioning. The government of the country also proves to construct new dams in this basin including Gibe IV and Gibe V. The key informants stated that there are additional potential sites for hydropower in the basin, which is expected, be used in the near future. Gilgel Gibe III (Gibe III) hydroelectric power project was constructed on the Omo-Gibe River and it is the second largest in the country with a potential of 1,870 MW, that is, estimated production capacity of 6,500 GWh a year. Moreover, several other dams were constructed in the basin including Gibe I and Gibe II (Velpuri and Senay, 2012).

Recreational use of water in the area is also common. There were several sites which are known for its waterfall like Ajora waterfall, Gibe Dam I, II and III. These are potential tourists' sites in the basin. In addition, the dams are used as pot spot for fishing, through which local community members participate in fishing activities for food and market use. Despite these huge potentials of water resources, the people of Ethiopia in the basin have benefited trifling so far. The management of the water resource is governed by several hindering factors; hence, the region is under water stress, while having huge water resource potential. People are still demanding for water in the basin despite having huge water resources.

Challenges of IWRM implementation in the basin

The result of the study shows that the implementation of IWRM is governed by biophysical, socio economic and hydro political factors. Undulating topography, climate variability, population pressure, deforestation, financial constraints, and lack of basin authority were the major challenges (Table 2).

The identified factors were interlinked, forming complex interaction. Detailed explanations and analysis of specified factors are presented as follows.

Biophysical challenges for IWRM in the basin

The undulating terrain of the basin hinders effective implementation of IWRM (Figure 3 and Table 3). The elevation at which the river flows is below 700 m.a.s.l, while the suitable land for cultivation by means of irrigation is found in highlands above 1200 m.a.s.l. Due to these reasons, Omo-Gibe River did not serve as irrigation in the upper and middle parts of the basin. Even if, an area of 2000 ha of lands is suitable for irrigation in the catchment at which the elevation is between 700 and 1200 m.a.s.l, it will be impossible to cultivate the region due to shortage of technology so far. This result is consistent with the findings of previous studies (Awulachew et al., 2007; Eyasu et al., 2015).

Moreover, recurrent land sliding due to undulating topography leads to land degradation. This in turn leads to water ecosystem pollution in the middle parts of the basin. The terrain feature in the basin also hinders satisfying water demand for domestic water uses; hence, integrating water demand with existing water potential is impossible in the catchment until today.

The basin potential is estimated to be 16.6 up to 19 BMC and the consumptive annual water demand is estimated to be 0.132 BMC, excluding hydropower and recreational use (Table 4).

It was noticed that an insignificant proportion of water is needed for use, while people are in demand for water in the basin. The Amharic proverb *Ye Abayin Liji Wuha Temawu,* meaning having huge resource with people in demand, is true in Omo Gibe Basin. It explicitly implies

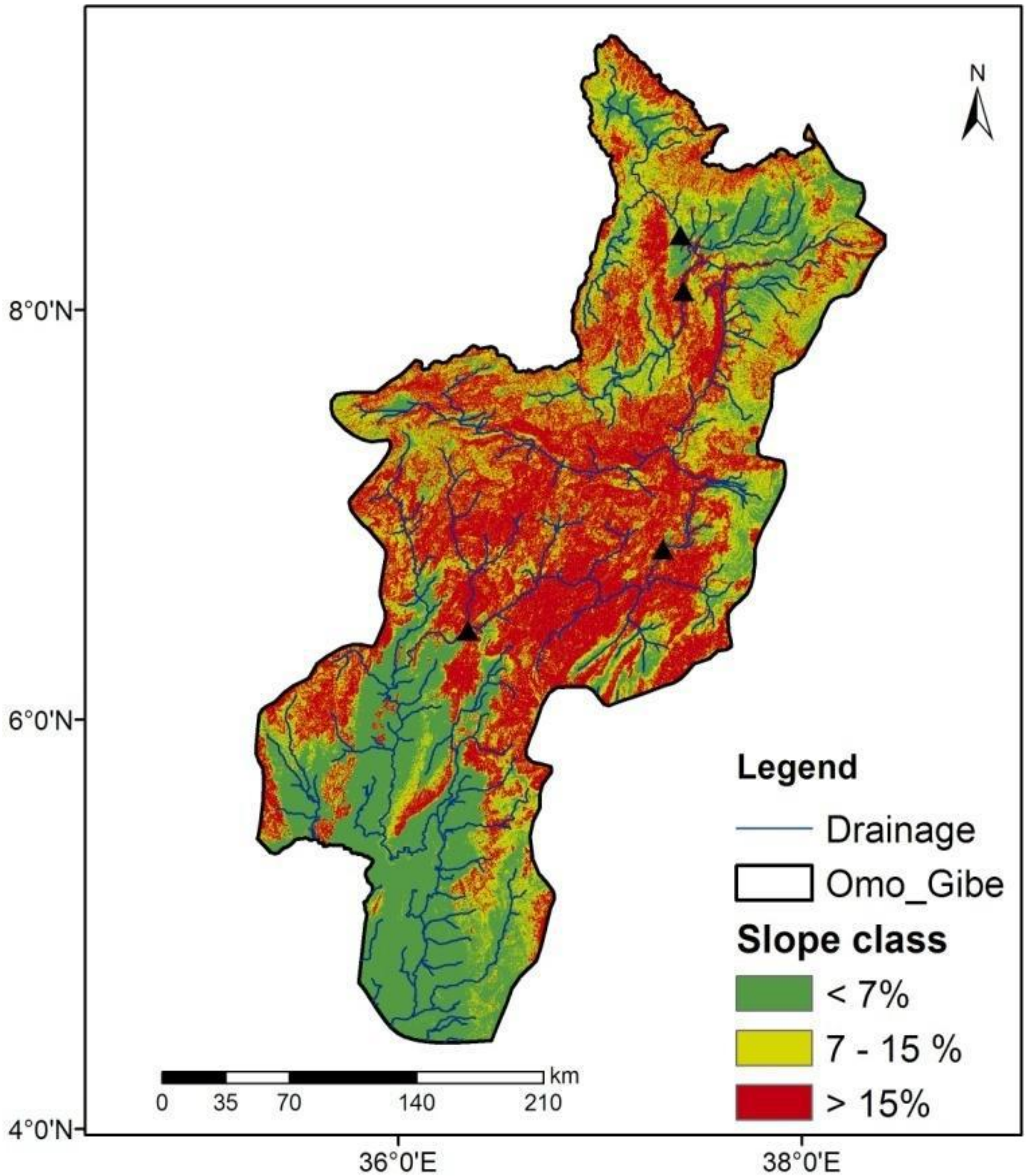

Figure 3. Slope classes in Omo Gibe basin.

Table 3. Respondents characterization of their land topography (slope).

Slope class	Respondents frequency	χ^2 (P value)
Steeply	162^b	
Moderate	51^a	0.000
Flat	35^a	

The different superscript letter indicates significance differences.

that the existence of ample amount of water only does not guaranty the wise use of water resources, the capacity, skill and knowledge also matters. Environmental degradation through destruction of indigenous tree species due to implementation of development projects was also encountered in the basin.

Table 4. Annual consumptive water demand at basin.

Zone	Region	Water demand (m^3)							
		Population	Domestic	Industrial	Institutional and commercial	Livestock	Irrigation	Recreational	Total
Bench Maji	SNNPR	692271	3790183.73	379018.4	568527.56	379018.4	758036.7	189509	6064293.96
South Omo	SNNPR	608358	3330760.05	333076	499614.01	333076	666152	166538	5329216.08
Hadiya	SNNPR	1306176	7151313.6	715131.4	1072697.04	715131.4	1430263	357566	11442101.8
Kaffa, Sheka	SNNPR	1139439	6238428.53	623842.9	935764.28	623842.9	1247686	311921	9981485.64
KembataTembaro, Halaba	SNNPR	722300	3954592.5	395459.3	593188.88	395459.3	790918.5	197730	6327348
Dawuro	SNNPR	519393	2843676.68	284367.7	426551.50	284367.7	568735.3	142184	4549882.68
Konta Special	SNNPR	96379	527675.025	52767.5	79151.25	52767.5	105535	26383.8	844280.04
Wolaita	SNNPR	1592530	8719101.75	871910.2	1307865.26	871910.2	1743820	435955	13950562.8
Gurage	SNNPR	1357577	7432734.08	743273.4	1114910.11	743273.4	1486547	371637	11892374.5
Yem Special	SNNPR	85601	468665.475	46866.55	70299.82	46866.55	93733.1	23433.3	749864.76
East Welega	Oromia	1393170	7627605.75	762760.6	1144140.86	762760.6	1525521	381380	12204169.2
Jimma	Oromia	3115472	17057209.2	1705721	2558581.38	1705721	3411442	852860	27291534.7
West Shoa	Oromia	2389265	13081225.9	1308123	1962183.88	1308123	2616245	654061	20929961.4
Total					-				0.132 BMC

The key informants and focused group discussion strongly state that the development intervention significantly affects the natural ecosystem and it costs the biodiversity. The choice between environmental expenses and development is of the government, they suggest that it has to be sustainable development. The climate variability, which is manifested by its recurrent occurrence of extreme events like Flood and Drought, are common in the basin. Most respondents (86%) from the basin agree that drought and flood are the common challenges in the basin. Endalamaw (2015) citied in Eyasu et al. (2015) in a previous study reported that more than 19, 000 ha of land with 2.5 m depth of flooding happened in lower parts of the basin. Besides, there are hostile effects on irrigation development; the prevalence of malaria disease due to flooding is a major health challenge for the nearby community in the area.

Weak enabling environment

The commitment of Ethiopian government to implement IWRM at grass root level is less, while development of water resources policy and environmental protection policy of the country are part of the government's IWRM worth. Lack of basin authority, lack of skilled manpower in the water sector, less development in water research and water research institutions, as well as weak water resource conflict resolution were noticed. Also, they govern the implementation of the integrated river basin management in the area. Moreover, weak government institutional integration is observed in this basin. They plan, the needs, integration and coordination of the institution separately. The division is clearly observed in the upper and lower catchment. This finding is in line with the findings of a previous study (Yohannis, 2012). As a general principle, strong enabling environment is an important factor for sustainable water resource management. Moreover, in many instances, only a few people in the hierarchy of water management know and understand IWRM and often there is insufficient technical support to operationalize it. Most experts who were nominated for Water Management in the Woreda were not familiar with principles of IWRM. It indicates that the lesson for capacity building is essential for better implementation of IWRM. There are few studies and data on ground water resource. The previous empirical study of Eyasu et al. (2015) establishes that inconsistence and absence of data are the challenges in the basin.

Weak community participation

Weak community participation in the development intervention and wrong traditional perspectives in relation to water use is a challenge for the basin. Local community thinks the *Water is a free gift from God* (Table 5).

This thought contradicts with the guiding principles of IWRM. Hence, they are not willing to pay for water uses. The community does not consider the opportunity costs of water. In line with this, Meshesha and Birhanu (2015) found weak community participation in Chena Woreda, Kafa Zone, south west parts of Ethiopia. Similarly, the finding of Meshesha and Birhanu (2015) concludes that watershed management practice is embedded with weak community participation. In contrast with this, Wolancho (2015) concludes that achievement in rehabilitating degraded lands are seen as excellent lessons for future efforts and the participation of community in watershed development was acknowledged. In line with this finding, the study in watershed management intervention in Berki watershed in northern Ethiopia revealed that step-by-step community participation has created a sense of ownership. Moreover, several studies witnessed that the northern parts of the country was recognized with its high level of community participation in the country (Jembere, 2009). Most previous studies including all aforementioned literatures agree that, in spite of having different status of community participation in water management intervention, their use trend shows that users are extracting high amount of water resources than their demand. Similarly, users are cost less amount than the benefit they get. Therefore, it was agreed that the recent use cost of water will not guarantee the sustainability of its future uses.

Lack of basin authority and weak capacity building

Water resource boundaries do not coincide with political boundary. Water flows from upstream to downstream through gorge, while politics form boundaries suit its interest. The regional boundary delineation of Ethiopian government classified Omo- Gibe basin into two regional states: Oromia and SNNPR. The Oromia regional state includes Jimma, East Welega and West Shoa zones, and SNNPR includes Kaffa zone, Gurage zone, Hadiya zone, Dawuro zone, Wolaita zone, Gamo-Gofa zone, South Omo zone and Yem special Woreda (Figure 4).

This indicates that the basin boundary and regional boundary are different. It was discovered that different regions and different zones in the same region manage water resource differently. There were no officially recognized body to bring those different interests into common interest and no one is responsible to integrate water management in the basin, except Ministry of Water, Electric and Energy at federal level. In spite of having 12 river basins in the country, only three, Awash, Abay and Rift Valley, basins have their own basin authority. However, Omo-Gibe basin do not have the central planning basin authority. This is one of the limiting factors for success implementation of IWRM. Integrated water management seeks grass root management institution rather than ministerial office. Lack of skilled manpower in water resource management sector is another hindering factor of IWRM. Most of the respondents (99.99%) assured that there are only few experts at zonal in this sector. None of the respondents report about the presence of expert in kebele level, while experts are in high demand.

Demographic pressure

The population pressure is also the challenge for the catchment. The middle part of the basin is densely populated as compared to the entire parts of the country (Table 6).

Increase in population growth leads to utilizing of forest resources beyond its carrying capacity. Similarly, pervious study shows that the increased demands for water and land in Indonesia as a consequence of the population growth and economic development has reportedly have been accelerated from year to year (Fulazzaky, 2014). All respondents associated the deforestation of natural forest with human population pressure in their locality. Hence, the expansion of agricultural land is responsible for environmental degradation and forest resources in the basin. Shifting cultivation is used in Kaffa zone, in which large natural forests were destroyed. Finally, this has led to pollution of water resource through erosion, which worsens water quality and uses.

Land use land cover change and environmental degradation

Deforestation, Land sliding, Flooding and Drought are also repeatedly reported by respondents in the basin.

During the field observation, it was observed that Bushlands were cleared and used for charcoal production (Figure 5, Table 7), since the land is required for laying water for hydropower development (Gibe III).

Other empirical studies also states that poor land management, flood and drought lead to complications in the basin. Change in climatic condition result in huge form of flooding and rise in evaporations. Geo hazard problems like landslides, gullies and siltation are some of the anticipated challenges and environmental problems threatening the long benefits of the dam in Omo Gibe basin (Kebede, 2012).

Financial constraints and poverty

According to a focused group discussion, poverty is one

Table 5. Community understanding about water.

Variable	Response frequency		Percentage	
	Yes	No	Yes	No
Water is finite response	103	145	58.46774	41.53226
Water is social good	248	0	100	0
Water has economic value	96	152	61.29032	38.70968
Water is free gift of God	248	0	100	0

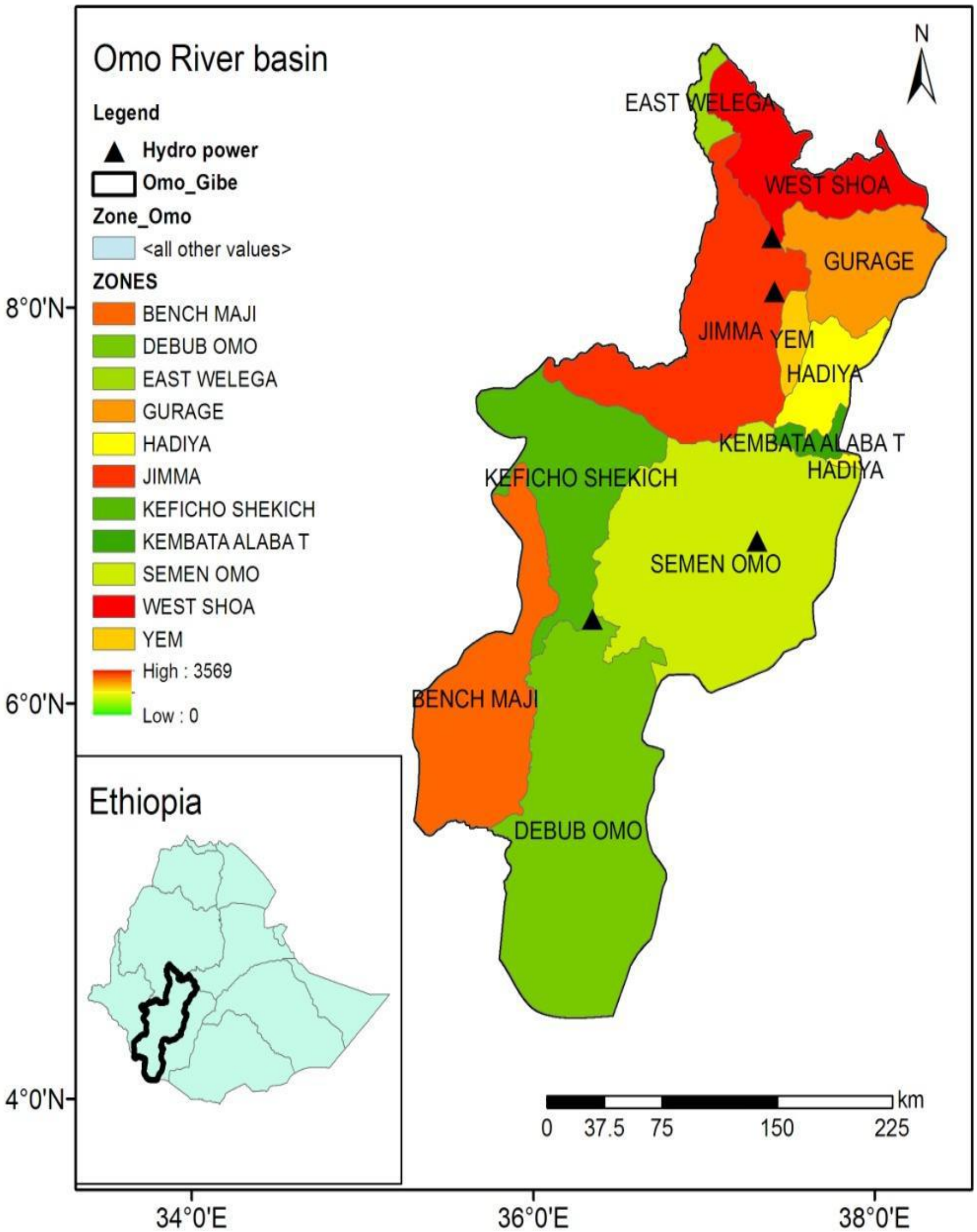

Figure 4. Political administrative boundaries in Omo-Gibe Basin.
Source: Eyasu et al. (2015).

Table 6. Population of Omo-Gibe Basin.

S/N	Zone/Woreda	Region	2007 (from CSA)	2017	Projected for 2027
1	Bench Maji	SNNPR	652531	672107	692271
2	South Omo	SNNPR	573435	590639	608358
3	Hadiya	SNNPR	1231196	1268132	1306176
4	Kaffa, Sheka	SNNPR	1074030	1106251	1139439
5	KembataTembaro, Halaba	SNNPR	680837	701263	722300
6	Dawuro	SNNPR	489577	504265	519393
7	Konta Special	SNNPR	90,846	93572	96379
8	Wolaita	SNNPR	1501112	1546146	1592530
9	Gurage	SNNPR	1279646	1318036	1357577
10	Yem Special	SNNPR	80687	83108	85601
11	East Welega	Oromia	1313196	1352592	1393170
12	Jimma	Oromia	2936631	3024730	3115472
13	West Shoa	Oromia	2252111	2319675	2389265
Total			14155835	14580516	15017931

For 2027 is projected using 2007 CSA census data

Figure 5. Bushlands firing for site clearance.

Table 7. Land cover dynamics of the basin.

S/N	Land use type	Area km^2 (2010)	Area km^2 (2015)	% of land use type
1	Woodland	23794	13794	30.02
2	Intensive cultivation	23637	24038	29.82
3	Bushlands	7978	3125	10.06
4	Forest	6722	6320	8.48
5	Grassland	5906	3890	7.45
6	Moderate cultivation	5609	5950	7.08
7	Marsh	2103	1570	2.65
8	Shrubland	1111	250	1.4
9	Bare soil	1037	1037	1.31
10	Plantation and fallow	1001	1001	1.26
11	Open water	321	18242	0.41
12	Afro-Alpine	38	38	0.05
13	Urban	18	20	0.02

of the major challenges in the basin. This intern leads to financial constraints to have modern technologies in water resource management. As most key informants stated that the challenge is not budget shortage, but also unwise use through improper allocation is also prevalent. Long transaction of budget from Federal to local government is confronted for the basin. Besides, the corruption of public budget is the bottleneck for the catchment in particular and for the country at large. Similarly, the previous studies in Africa with particular focus on Ethiopia conclude that Ethiopia faces a range of challenges in water management, with levels of service provision for water supply and sanitation that are amongst the lowest in the world. There are very low levels of irrigation development and challenges in areas such as hydropower development, disaster mitigation and ecosystems management (Jembere, 2009; Dowa et al., 2007) in the country.

Gender disparities in the basin

Watershed management is an important planning unit for sustainable natural resource management, in which the roles and responsibilities of women and men has to be clearly mainstreamed and benefited equally. Empowering women in water resource management and development is essential. Women and men use water for many purposes such as drinking, domestic purposes, livestock, gardening, irrigation, tree growing, fisheries, food processing and other cultural and business purposes. The evidences found from this study shows that the responsibility of fetching water is the obligations of women. The responsibility of women is rounded with homestead activities. The involvement of women in formal water management is less, compared to men. The involvement of women in decision making for watershed management is invisible. Moreover, the representation of women in water resource management sector is still very small; nevertheless, they are the guardians of family health and hygiene and providers of domestic water. Women, therefore, are the primary stakeholders in the homes as far as the issue of water provision and safeguarding is considered. Yet, men in the basin mostly make decisions on water systems. Contrary to this, as a general principle of IWRM, women play a central part in the provision, management and safeguarding of water (GWP, 2000).

Origin in the academia

As its name indicates, IWRM require multidisciplinary and/or interdisciplinary research and development intervention. However, in Ethiopia in general and in Omo-Gibe Basin in particular, water resources management teaching and research is considered within the exclusive domain of the natural sciences. Particularly, IWRM is under the umbrella of the fields of engineering and natural sciences. This is because of its origin in the academia, where it is considered as pure natural science discipline and excluding social sciences. To be effective, IWRM requires socio-economic and political concern in its implementation. However, the social science disciplines are discouraged, to say the least, from playing the vitally needed role. Similarly, Yohannis (2012) suggest an interdisciplinary and thematic research development in Lake Tana basin.

Opportunities for implementation of IWRM in the basin

Contrary to its hindering factors, Omo Gibe River basin has numerous opportunities that has to be used for further intervention and development of the region. To mention some, policy support of the principles of IWRM, local community cultural integration, tourism development potential of the basin, commitment of government on watershed management and development of international collaboration and support for IWRM were commonly reported potentials of the basin.

Cultural integration

The integration of the society of upstream and downstream, through long time cultural development like in marriage, has great contribution for the effective implementation of IWRM. The Kafficho society has culturally bonded with Dawro and Yem society, Dawro with Wolaita and Hadiya, Hadiya with Gurage and Yem. This cultural bondage has potential positive contribution for IWRM, since the society has a long time relationship in the basin through helping each other. According to FGD and Key informants, this integration had significant contribution in conflict resolution and wise resource sharing in the basin.

Water resource policy support of IWRM

The rule of law in the country, Constitution of the Federal Democratic Republic of Ethiopia (1987), gives due focus on IWRM; therefore, it has constitutional support and legal ground as stated under Article 40/3, 51/5, 51/11. Moreover, it has policy support. The presence of well-designed water resources policy of the country is an opportunity for IWRM. Considering water as a social and economic good, the principle of cost recovery, acceptance of the basin as a unit of planning, decentralized management, equitable and reasonable water allocation, capacity building, and research and development are the most important concepts incorporated in the policy (MoWR, 1999). In addition, the Ethiopian Water Resources Management Proclamation No. 197/2000 also has special provision for integrated water resource management. The purpose of the Proclamation is to ensure that the water resources of the country are protected and utilized for the highest social and economic benefits of the people of Ethiopia, to follow up and supervise that they are duly conserved, to ensure that harmful effects of water are prevented, and that the management of water resource is carried out properly. The policy and legal support gives due recognition to IWRM and promotes sustainable utilization of the resource. In addition, previous studies (Yohannis, 2012; Awulachew et al., 2007; Meshesha and Birhanu, 2015) support this result.

Development of international collaboration and support for IWRM

This basin encompasses several well-experienced universities including Arbaminch, Jimma, Wolyita-Sodo, Bonga and Jinka. The research collaboration among these universities in the basin is good opportunity. These institutions did not only make local collaboration but also international. For instance, Jimma University collaborated with Heinrich Boll Foundation and they are working on Environment and Capacity building. Arbaminch University had long time teaching and research experience on water sector and great potential of the basin for academia. The newly emerging universities (Bonga and Jinka) have collaboration initiation with higher institution both at national and international level. In addition, United States government supported a project that promotes IWRM in Ethiopia. Good international integration and diplomacy with neighboring a country, Kenya, using Win-win approach for water resource sharing is an opportunity not only for the basin, but also for the country.

Tourism potential of the basin

The development of tourism industry in the basin also has positive contribution on IWRM. Diverse topography, diverse ecosystem and diversity of natural and human made resources were special attraction of tourism industry in the basin. This industry also opens the door for locals to get financial resource for further development.

Watershed management initiatives of Ethiopia

Watershed management campaign, which was initiated by the government in Ethiopia in general and in Omo Gibe basin in particular, has positive contributions on IWRM. The previous studies conclude that watershed management campaign has a successful accomplishment in the basin (Wolancho, 2015).

Conclusion

The Omo-Gibe River basin has the right to exist in harmony with its ecosystem to function in a sustainable manner. The human intervention through complex and interconnected linkage has been compromising the ability of the basin to function in its natural role. Depletion of the basin is the diminution of community. The Omo-Gibe River basin has experienced different computing water demands including water for agriculture, domestic uses, hydropower, irrigation and recreational uses. IWRM is the art of solution for sustainable water resource management. In Omo-Gibe River basin, several factors limit the successful implementation of IWRM. Rapid population growth, environmental degradation, steep topography, climate variability, lack of river basin authority, conflict of interest over natural resources, gender disparity, origin of academia, lack of skilled manpower, unwise uses of financial resources and poverty, are the hindering factors for IWRM. The government of the country officially recognized IWRM as a vital tool and adopted in its policy document. Nevertheless, the efforts done so far in the basin and the implementation of IWRM are not satisfactory. On the other hands, there are also several success factors for effective implementation of IWRM in the area. There are cultural integration**,** water resource management policy in the country, and tourism development in the basin; thus, development of watershed management campaign in the country has been considered as a good opportunity for IWRM. Therefore, effective implementation integrated water resource management is an important tool for the sustainability of the basin.

Recommendation

Through understanding a number of hindering factors of the implementation of IWRM in Omo-Gibe basin, the following recommendations were forwarded:

(1) Establishing the Omo Gibe River Basin with the full mandate of managing the resources in the basin is important so that the government, that is Ministry of Water, Electric and energy, could play its managerial role through actualizing the authority in the basin.
(2) Capacity building through establishing water research institutions and proving training at higher level is also essential.
(3) An enabling environment should be translated from principle into practice, to bring the stated objectives into policy in the country.

(4) Further investigation has to be conducted on the constraints and factors hindering integrated water resource management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ABBREVIATIONS

BMC, Billion cubic meters; **CSA,** Central Statistics Agency; **FGD,** focused group discussion; **IWRM,** Integrated Water Resource Management; **MEA,** Millennium Ecosystem Assessment; **MoWR,** Ministry of Water Resources; **SNNPR,** Southern Nation Nationalities and Peoples Region; **SPSS,** Statistical Package for Social Science; **WGP,** Global Water Partnership.

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Full Length Research Paper

Influence of anthropogenic and ecological factors on stand structure of *Pterocarpus erinaceus* Poir. in Sudanian and Sahelian zones of Burkina Faso and Niger

Habou RABIOU[1*], Kossi ADJONOU[2], Issiaka ISSAHAROU-MATCHI[1], Kossi Novinyo SEGLA[2], Babou André BATIONO[3], Adzo Dzifa KOKUTSE[2], Ali MAHAMANE[1] and Kouami KOKOU[2]

[1]Université de Diffa, BP78 Diffa, Niger.
[2]Laboratoire de botanique et écologie végétale Université de Lomé Faculté des Sciences BP 1515, Lomé, Togo.
[3]Institut de l'Environnement et de Recherches Agricole (INERA) du 04 BP 8645 Ouagadougou 04, Burkina Faso.

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Pterocarpus erinaceus **is a popular tree for medicinal and fodder uses in the Sudano-Sahelian belt of West Africa. It is also used for its wood.** ***P. erinaceus*** **is one of the most exploited tree species in many countries in West Africa. Planks and logs have been exported towards the South-West Asian countries for ten years. This paper analysed the demographic structure, the ecological characteristics of natural stands of** ***P. erinaceus*** **and level of human pressure they suffer in two agro-ecological zones of Burkina Faso and Niger. Transects were installed in four forests of which two were in the Sahelian zone of Niger and two were in the Sudan region of Burkina Faso. Measurements and observations focused on the dendrometric parameters, soil type, vegetation type and the presence of termite mound. The traces of debarking and pruning were noted. Trenching traces have been categorized into 3 classes according to their intensity. The Sudanian zone shows higher densities than the Sahelian zone. The largest individuals of** ***P. erinaceus*** **(the mean diameter and the highest average height) are observed in the W regional park (57.7 ± 18.6 cm and 10.8 ± 2 m) although this park belongs to the Sahelian zone. In all areas, distribution of diameter classes are bells, characteristics of aging stands with predominance of older individuals. Dendrometric characteristics vary according to the agro-ecological zones, soil type and vegetation. Twenty-one percent of** ***P. erinaceus*** **inventoried in the Sahelian zone and 13% in Sudanian area are close to an anthill.** ***P. erinaceus*** **is a species of Sahelo-Sudanese areas, analysis of its demographic structure shows that individuals of small diameter are very poorly represented in all forests. The species is exploited much more in Sahelian zones for feed supplements. The soil type and vegetation type influence the growth of** ***P. erinaceus*****. Indeed, the strongest individuals were observed on soil clay loam, sandy loam soil and woodland.**

Key word: *Pterocarpus erinaceus*, demographic characteristics, Sahelian and Sudanian zones, Niger, Burkina Faso.

INTRODUCTION

In Africa, natural resources play a very important role in the lives of particularly rural populations (Ouedraogo et al., 2006). The Sahelo-Sudanian band in West Africa faces serious problems of imbalance in natural ecosystems and accelerated degradation of natural resources. The most important degradation observed in these ecosystems results in a reduction of their surface area and, above all, an increase in the mortality rate or even the extinction of certain woody species, resulting in a significant modification of the vegetation structure (Bationo et al., 2001a, 2005; Rabiou et al., 2015).

The increase in demand for woody species for various uses (food, pharmacopoeia, firewood, handicrafts, fodder, etc.) is increasing rapidly in many localities due to rapid growth of human population and livestock (Ouédraogo, 2007). Although *Pterocarpus erinaceus* Poir. is widely appreciated for its wood, fodder and medicinal products (Ouedraogo et al., 2006; Sylla et al., 2002; Rabiou et al., 2015) it is belong to the species currently threatened in West Africa. The species is particularly threatened in Burkina Faso and Niger where it undergoes severe pressure, affecting its capacity for natural regeneration (Touré, 2001; Ouedraogo, 2007). During the dry season, *P. erinaceus* foliage is the most widely sold forage in Niger and Burkina Faso (Sanou et al., 2011). In 1990, more than 1,400 tons of fresh foliage, 78% of which were obtained from *P. erinaceus*, was sold in Bamako (Mali) as feed for small ruminants (Duvall, 2008). In Burkina Faso, the species represents more than 10% of the eleven main woody species used in handicrafts. In Niger, according to the forestry service responsible for the control and repression of offenses in the Tamou reserve, during the dry season (April to June), more than 90% of fines concern the mutilation of *P. erinaceus* by transhumant shepherds. The species is the subject of a hay exploitation by the shepherds especially in the dry season at the moment when the herbaceous fodder begins to miss. The constant pruning operates as a hindrance to the development of buds towards flowers and fruits and dangerously compromises the ability of the species to disseminate its seeds and possibly the regeneration in natural condition (Rabiou et al., 2015).

In the Sahelo-Sudanian countries, local species still face socio-cultural constraints such as use and clearing, and insufficient scientific knowledge about the ecology of these species (Bationo et al., 2001a, 2010). This paper analyzes the influence of pruning and debarking on the demographic structure of *P. erinaceus* natural stands in the Sahelo-Sudanian belt of Burkina Faso and Niger. It is also a question of analyzing the dendrometric and ecological characteristics as well as the level of pressure depending not only on the agro-ecological zones but also on the status of the forests that harbor the natural stands of this species. The results will allow better decision-making regarding the regeneration and exploitation of the species.

MATERIALS AND METHODS

Study areas

Sahelian zone (Niger)

In Niger the study was conducted in the Tamou Wildlife Reserve and in the Regional Park of W. The Tamou Wildlife Reserve is a pastoral reserve. It is located between 12°28 'and 12°50' N and 2°06'and 2°24' E (Figure 1) (Diouf et al., 2010). It covers an area of 76,000 ha. The mean annual rainfall is 606 mm (average from 1988 to 2007) at the Tamou rainfall station. The average annual temperature is about 28.9°C. The highest average monthly maximum temperatures are recorded in April (39.5°C) while the minimum temperatures are observed in December and February (16.1°C). The vegetation of the Tamou Fauna Reserve is a mosaic of clear forests often formed by *Anogeissus leiocarpus* and *P. erinaceus*, tree savannahs, shrub savannahs and grass savannas. The woody flora is composed mainly of the Combretaceae which dominant species include *Guiera senegalensis, Combretum nigricans* and *Combretum micranthum* (Mahamane et al., 2007). The W regional park is a transboundary protected area straddling Benin, Burkina Faso and Niger. The study was conducted in the Niger portion between 11°00'and 12°35' N and 2°00'and 3°50' E (Figure 1). The average annual temperature is 30°C over a period of 20 years and an average annual rainfall of 704.7 mm (Diouf et al., 2010).

Sudan (Burkina Faso)

In Burkina Faso, the study was conducted in Cassou and Laba forests (Figure 1). The Cassou forest is located in the province of Ziro with an area about 29 515 ha. The average temperature is of 29°C, the average annual rainfall is around 900 mm between mid-June and the end of September (Sawadogo, 2009). The vegetation of the area is made up of savannah woodland, savanna with islands of clear forest and gallery forest along streams. The classified forest of Laba is located in the province of Sanguié and is coordinated 11°40' N and 2°50'W (Figure 1). The average annual rainfall is about 907±157 mm. The average annual temperature is 24°C with a thermal amplitude of 15°C. The vegetation is dominated by the shrub savannah and wooded riparian formations along the rivers (Sawadogo, 2009).

Characterization of the demographic structure

Sampling

Given the low density of *P. erinaceus* in these areas, the sampling in this study focuses on the band transect method (Rabiou et al., 2015). Two perpendicular transects of north-south and west-east direction, each about 200 m in width, have been established in each forest in order to characterize stands of *P. erinaceus* (Figure 2). The crossing point of these two transects corresponds to the center of the forest. The use of two transects makes it possible to take into account the heterogeneity of the forests studied and to inventory enough individuals of *P. erinacus* for estimating their

*Corresponding author. E-mail: rabiouhabougarba@yahoo.fr.

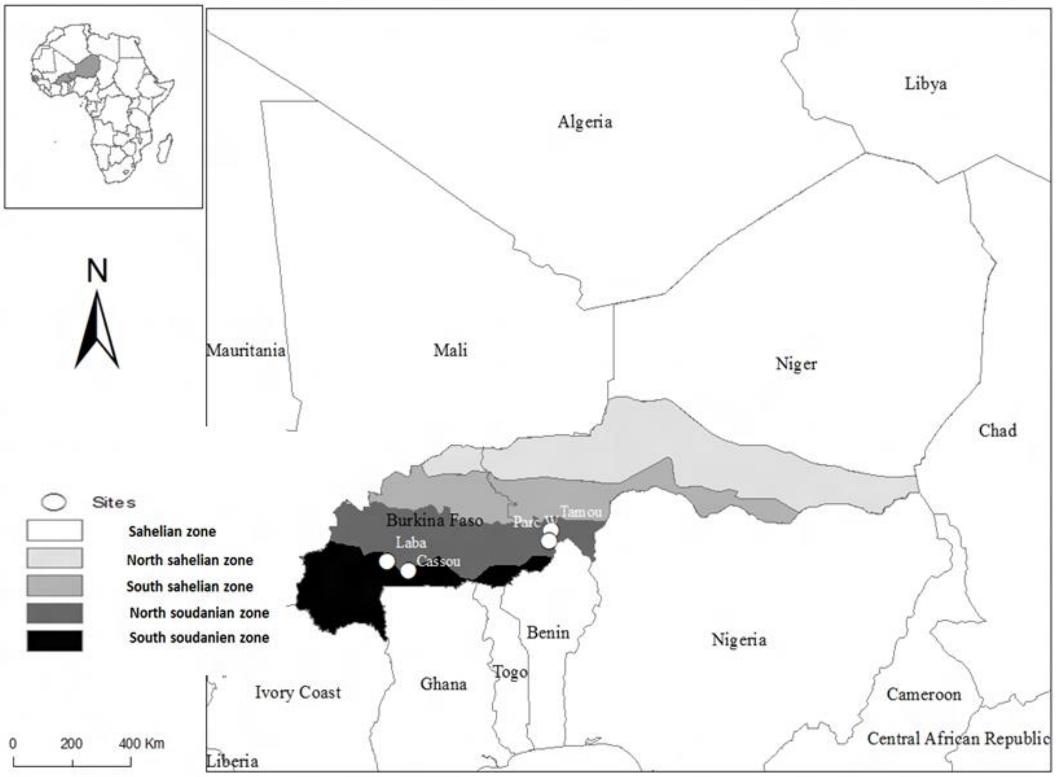

Figure 1. Location of study sites.

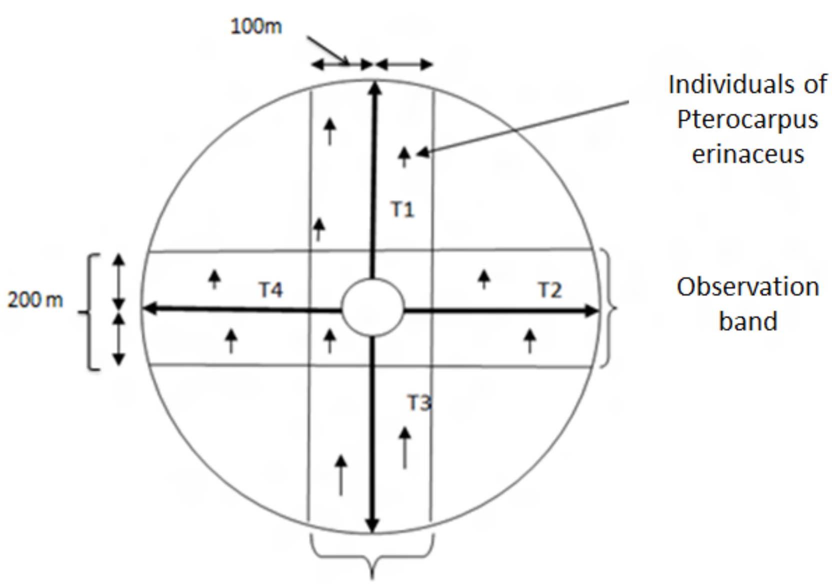

Figure 2. Device for collecting data on *P. erinaceus.*

density (Table 1).

Data collection

In each observation band an azimuth was fixed using a GPS. Along this azimuth, all individuals of *P. erinaceus* with a diameter of 1.30 m greater than or equal to 5 cm are measured. The distance between the individual and the direction perpendicular to the azimuth was estimated using a laser rangefinder to not exceed 100 m on either side of the azimuth. Measurements were carried out on the diameter at 1.30 m from the ground, the total height, the height

Table 1. Characteristics of observation bands.

Characteristics of strip transects	Sudanian zone (Burkina Faso)		Sahelian zone (Niger)	
	Laba	Cassou	Tamou	Parc W
Total length (Km)	3.1	1.7	9.8	6.4
Area covered (ha)	63.24	34.04	197.3	128.02

of the stem, the two perpendicular diameters of the crown respectively using a forest compass for large diameters, a graduated rod and a meter ribbon. The threat to the individual (trace of pruning or debarking), the type of soil and vegetation formation in which the individual is found, and its presence on a termite mound or not have been noted. The texture of the soil by the tactile method (Ambouta, 1984) in the first 20 cm was determined using the tactile method. Table 1 summarizes the distances travelled and the areas covered.

Data analysis

Dendrometric characteristics

The data collected on the stand of *P. erinaceus* were subjected to the analysis of variance in order to compare the dendrometric parameters according to the types of vegetation formation, the type of soil and the threats. The general linear model was used using R and Minitab softwares. The density (N), the basal area (G) and the stand Lorey height (H) were calculated.

$$N = \frac{n}{s}$$

With n: the total number of individuals and s the area covered in ha. The basal area G is the sum of the cross-sections of all individuals of *P. erinaceus* returned in m^2/ha:

$$G = \frac{\pi}{4s}\sum_{i=1}^{n} di^2$$

Where di: the diameter in m of the individual i and s the area covered in ha.
The mean height of Lorey (HL) is the average height of individuals weighted by their basal area, expressed in m (Philip, 2002).

$$H_L = \frac{\sum_{i=1}^{n} \text{gi hi}}{\sum_{i=1}^{n} \text{gi}} \qquad \text{avec gi} = \frac{\pi}{4} di^2$$

Where gi: the basal area of the individual i in m^2,
h: the height of the individual i in m and
di: the diameter of the individual i.

Demographic structure

Minitab 16 software was also used to estimate the parameters of the Weibull theoretical distribution from the observed diameters and heights data. To ensure a good fit of the observed structure to the Weibull theoretical distribution, the SAS software was used for an adjustment test based on log-linear analysis.

Weibull distribution of diameters

The Weibull distribution with 3 parameters (a, b and c) is characterized by great flexibility of use and a great variability of form. Its probability density function, f (x) is presented as follow (Rondeux, 1999).

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

Where x is the diameter or height of the trees and f (x) its value of the probability density function.
a = is the position parameter
b = is the scale or size parameter
c = is the shape parameter related to the observed structure.

RESULTS

Dendrometric characteristics and stand structure

The findings are made to establish the dendrometric characteristics of *P. erinaceus* according to the agro-ecological zones (Table 2). The analysis of this table shows that the largest individuals of *P. erinaceus* (the mean diameter and the highest average height) are observed in the W regional park (57.7±18.6 cm and 10.8±2 m) although this park belongs to the Sahelian zone. Trees in the Tamou Wildlife Reserve, which is a buffer zone of Park W, have an average diameter of 36.8±12.6 cm and an average height of 9.20±2.3 m, much lower than those recorded in the Park W (P <0.001) although the climatic and ecological conditions appear to be the same. In the Sudanian zone, the density is higher with 9.41 trees/ha in the Cassou forest and 2.84 trees/ha in the Laba forest, compared to only 1.82 individuals / ha in the Park W and 0.75 tree/ha in the Tamou fauna reserve in the Sahelian zone.

The structure of stands of *P. erinaceus* shows that the best represented individuals are in the diameter classes between 15 and 45 cm and between 35 and 65 cm in Sudanian zone and Sahelian zone respectively (Figure 3). Young stands are almost absent. In general, the distributions of diameter classes in all plant recorded are adjusted to the theoretical Weibull distribution (P> 0.05) with c> 1 form parameters, showing thus the characteristic of stands with predominantly elderly individuals.

The height structure of *P. erinaceus* stands shows a bell distribution in the Sudanian and Sahelian zones

Table 2. Dendrometric characteristics stands of *P. erinaceus.*

Parameter	Sudanian zone (Burkina Faso)		Sahelian zone (Niger)		Probability
	Cassou	Laba	Parc W	Tamou	
Diameter (cm)	25.49±7.8^{b}	33.63±10^{a}	57.7±18.6^{c}	36.89±12.6^{a}	<0.001*
Height (m)	8.07±1.6^{b}	9.29±2.08 ^{a}	10.8±2.02^{b}	9.20±2.3^{a}	<0.001*
Commercial height (m)	3.53±1.05^{a}	3.95±1.42^{b}	4.35±1.5^{c}	3.65±0.9^{ab}	<0.001*
Basal area (m^2/ha)	0.54	0.286^{a}	0.524	0.089^{a}	<0.001*
Height of Lorey (m)	8.68	9.99a	11.62	10.24^{a}	<0.001*
Crown (m)	6.3±2.15^{ab}	6.25±2.48^{ac}	10.18±3.05	5.65±2.42^{bc}	<0.001*
Densityé (trees/ha)	9.401	2.84	1.82	0.75	<0.001*

Means ± standard deviation in a column followed by the same alphabet are not significantly different (P>0.05) according to Turkey's test.

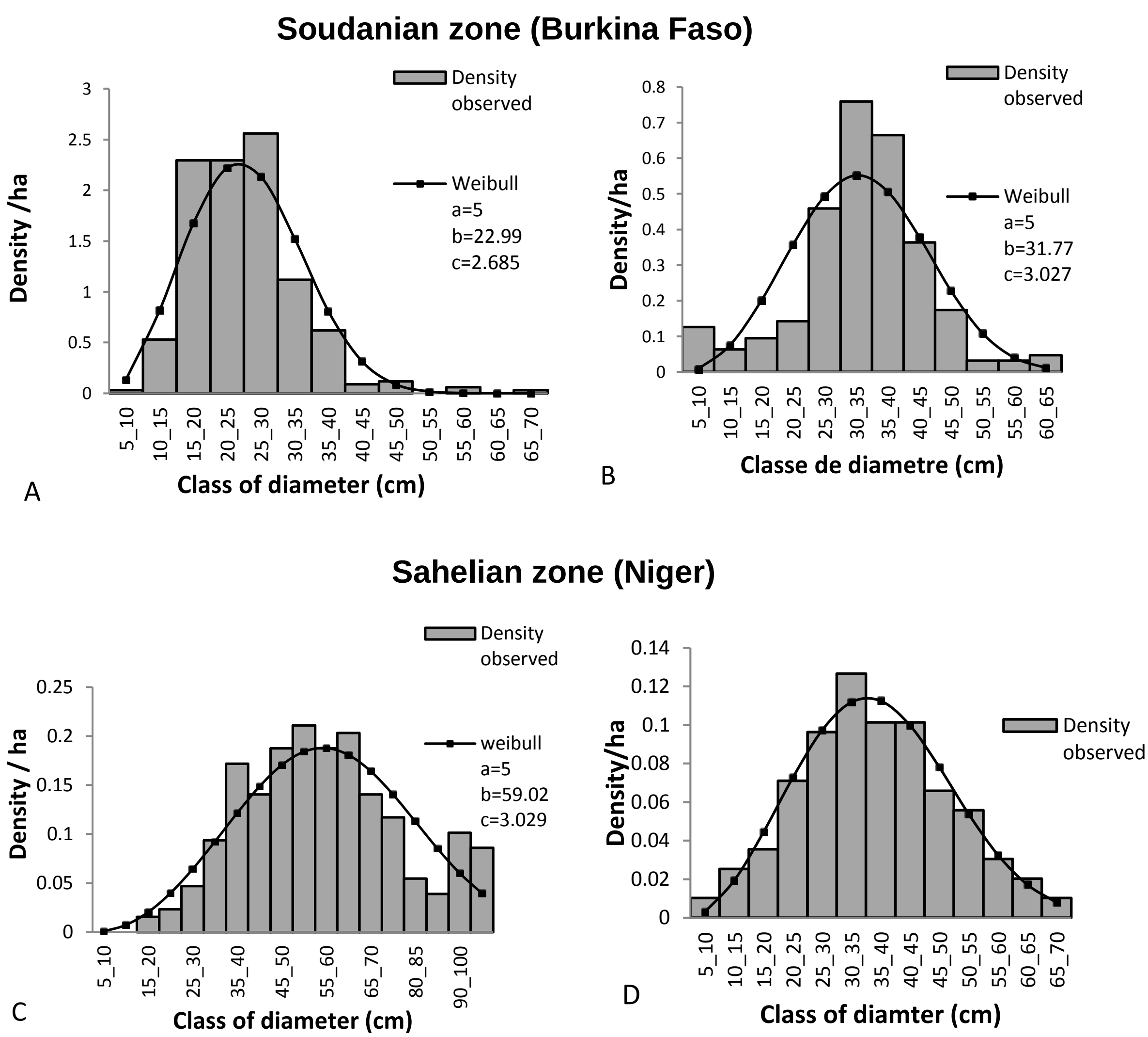

Figure 3. Diameter structure of *P. erinaceus*: forests of Cassou (A); Laba (B); Park W (C) and Tamou (D).

(Figure 4). The weak form parameter is observed in Cassou forest with c=2.785; on the other hand, the Park W where the largest individuals were recorded has a parameter of form c=5.522 of the theoretical distribution of Weibull. The variation of the parameer of form c expresses the frequency of young individuals. Indeed, the

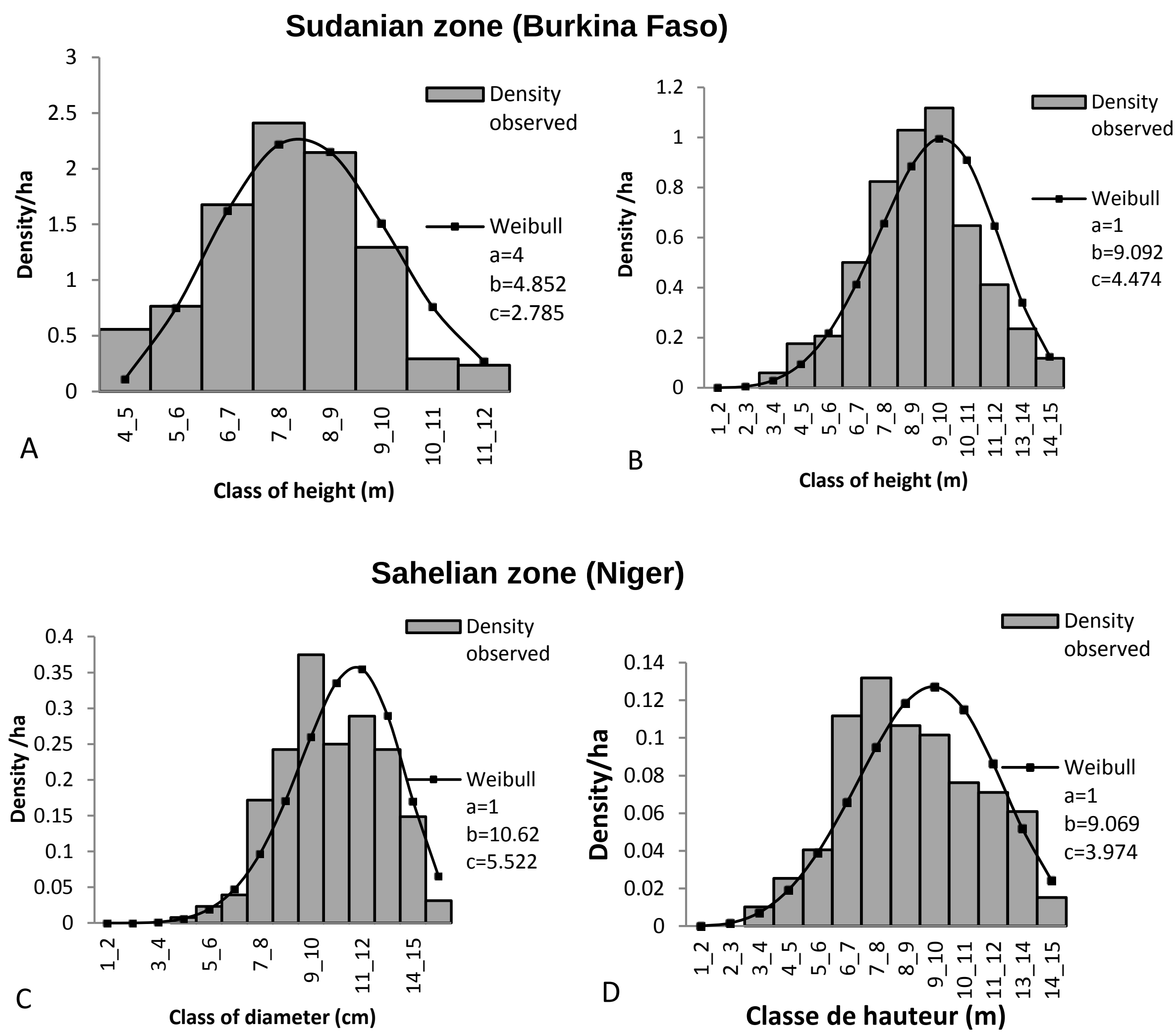

Figure 4. Structure in height of *P. erinaceus*: The forests of Cassou (A); Laba in (B); The Park W (C) and Tamou (D).

more c increases the more frequency of elderly individuals increases.

Effect of soil types on the variation of dendrometric parameters

Soil type appears to play an important role in the diameter and height growth of *P. erinaceus*. Clay loam soil and sandy loam soil are the best ecological preference of this species. Individuals growing on these soils are distinguished by their high dendrometric parameters (diameter, height and height); in contrast to clayey soil and sandy soils that have individuals of *P. erinaceus* whose dendrometric parameters are very low with statistically significant differences. Individuals of this species growing on laterite soil found only in the Sahelian zone, that is, in Niger, has an average diameter of 36.2 cm and an average height of 8.4±2.2 m (Table 3).

The sandy loam soil and the silty-clay soil also optimize the growing in height of the stem. These soils stand out with high values of mean stem heights respectively with 4.05±1.3 m and 3.97±1.3 m. The lowest height of the drum is observed from individual growing on clay soil. This result shows that the height growth of the stem is sensitive to the compactness of the ground. The observed difference is statistically significant ($P<0.001$) in general. The test, however, indicates that there are no statistically significant differences between the mean height of the *P. erinaceus* stem on clay loam and sandy loam soils. The difference is clearly significant between these soils and the group of silty, sandy lateritic and clayey soils in which there are no significant differences in mean height of the stems (Table 3).

Analysis of the effect of the soil type on the dendrometric parameters reveals that higher values were observed in Sahelian zone. These differences are strongly influenced by the stands aging in Park W with values on

Table 3. Variation of the dendrometric parameters stands of *P. erinaceus* as a function of the soil type.

Soil texture	Diameter (cm)	Height (m)	Commercial height (m)
Clay soil	23.9±13[b]	7.6±2.9[b]	2.8±1.1[b]
Laterite	36.2±12a	8.4±2.2[b]	3.5±0.6[b]
Limestone	29.4±7.5[b]	8.3±1.4[b]	3.5±1.1[b]
Silty clay	42.2±19.1[a]	9.7±2.2[a]	3.9±1.3[a]
Sandy	20.4±5.9[b]	7.2±1.6[b]	3.3±1.0[b]
Sandy-loam	38.9±17.5[a]	9.3±2.1[a]	4.0±1.3[a]
Probabilité	<0.001*	<0.001*	<0.001*

Means ± standard deviation in a column followed by the same alphabet are not significantly different (P>0.05) according to Turkey's test.

Table 4. Variation of dendrometric parameters according to soil type and agroecological zones.

Soil texture	Zones	Diameter (cm)	Height (m)	Commercial height (m)
Silty clay	Niger	49.21±20.1[a]	10.214±2.2[a]	4.01±1.3
	Burkina Faso	30.759±9.14[b]	8.982±1.8[b]	3.904±1.3
	Probability	<0.001*	<0.001*	0.416*
Sandy-loam	Niger	56.25±16.03[c]	10.726±1.88[a]	4.548±1.55
	Burkina Faso	29.975±10.07[b]	8.71±1.9[b]	3.8±1.08
	Probability	<0.001*	<0.001*	<0.001*

diameter, height and stem height of 57.7±18.6 cm, 10.84±2, (P <0.001) than those observed at Tamou with 37.04±12.85 cm, 9.38±2.29 m and 3.66±0.97 m respectively for the diameter, height and height of the stem. In the Sudanian zone, the difference between stands on sandy loam and silty-clay soils is not statistically significant (Table 4). Only these two types of soil have been observed both in the Sudanian zone and in the Sahelian zone. Stands on laterite soil are only observed in the Sahelian zone and on clay soil in the Sudanian zone.

Effect of the termite mound on the dendrometrics characteristics

Twenty-one percent of *P. erinaceus* inventoried in the Sahelian zone and 13% in the Sudanian zone were found in the environment of a termite mound. This environment influences the growth in diameter and height of trees. The differences are significant between individuals on termite and non-termite mounds in the same zone and between areas (P <0.05) except for the total diameter and height in Sahelian zone where the difference is not significant between (Table 5).

Exploitation of the resource

Table 6, shows the percentages of individuals pruned and individuals barked according to agro-ecological zones. Depending on the area, there are tracks of barking and pruning on the same individuals. In Park W where protection is integral, any track of debarking or pruning has been found. In Tamou Wildlife Reserve, which is adjacent to Park W, "85%" of individuals are pruned and 23% are barked. More than 60% of the individuals pruned are more than 50% of their crown. In the Sudanian zone in Burkina Faso debarking is not significant, but pruning remains the most widespread form of exploitation. Table 6 shows the summary of harvesting tracts, the average of the total height and the tree trunk varies according to the type of vegetation formation. The highest averages were recorded in the open forest. The differences are statistically significant (P <0.001) between light forest and other vegetation units but not significant between cultivated fields and savanna according to the test (Table 7).

DISCUSSION

The study of the natural stands of *P. erinaceus* conducted in Sahelian zone of Niger and in Sudanian zone of Burkina Faso shows that in addition to the ecological characteristics of the stations, protection is essential to ensure the development of species. Park W, because of its protected area status, while it is the least watered site, is home to the populations of *P. erinaceus*

Table 5. Variation of the dendrometric parameters of *P. erinaceus* on and off the termite mound.

Parameter	Sudanian zone (Burkina Faso)		Probability	Sahelian zone (Niger)		Probability
	On eroded termite mound	Outside eroded termite mound		On eroded termite mound	Outside eroded termite mound	
Height (m)	9.9±2.01	9.04±2.06	0.007*	10.8±1.8	10.02±2.3	0.005*
Diameter (cm)	36.9±9.82	33.03±9.4	0.014*	48.2±16.5	50±20.17	0.479
Commercial height (m)	4.33±1.47	3.80±1.38	0.027*	4.07±1.16	4.08±1.4	0.950

Table 6. Summary of operating traces.

Zone	Site	Debarking (%)	Pruning (%)	Intensity of pruning	
				25 - 50%	>50%
North sudanian	Cassou	2.5	70.5	31.5	68.4
	Laba	7.2	81.2	31.29	68.7
South sahelian	ParcW	0	0	0	0
	Tamou	24.3	85.2	39.37	60.62

Table 7. Influence of vegetation type on total height and stem height of *P. erinaceus.*

Land use type	Total height (m)	Commercial height (m)
Fields	8.3±1.3^{b}	3.31±1.0^{b}
Clear forest	9.5±1.8^{a}	3.96 ±1.3^{a}
Savannah	8.1±1.7^{b}	3.41±1.1^{b}
Probability	<0.001*	<0.001*

Means ± standard deviation in a column followed by the same alphabet are not significantly different (P>0.05) according to Turkey's test.

with the largest diameters and heights. The contribution of protection in the conservation of endangered species in the Sahelian and Sudanian zones was also reported by Traoré (2013) in Burkina Faso. However, the highest densities of *P. erinaceus* observed in the Sudanian zone are due to the best ecological conditions which are favorable to the establishment of the species. Indeed, the Sudanian zone corresponds to the most watered zone of our study zone, with a rainfall much higher than that observed in the Sahelian zone. The Cassou forest has a density of 9.4 trees / ha followed by the Laba forest with 2.8 trees per ha, far in front of the W Park and the Tamou Wildlife Reserve. These densities are considerably lower than those found by Glee et al. (2008) in the Wari Maro forest in Benin (22.8 trees / ha in the savanna and 23.3 trees / ha in the open forest), which are much lower than those found by Adjonou et al. (2010) in the central plain of Togo (114±1.1 trees / ha in harvested areas and 136±1.6 trees/ha in fully protected areas).

On the different sites, the large *P. erinaceus* (diameters and heights) were observed on deep silty-clay and sandy loam soils generally located beside depressions where water conditions are favorable. The species is, however, not very present on hydromorphic soils rich in clay. Several authors have reported the relationship between soil type and growth (Goulard et al., 1995; Bationo et al., 2010) and its impact on the spatial distribution of woody species (Grimaldi and Riéra, 2001; Clark et al., 1998, Condit et al., 2000, Bationo et al., 2005). Twenty-one percent of *P. erinaceus* inventoried in the Sahelian zone and 13% in the Sudanian zone are in the environment of a termite mound. The individuals on these microsites are distinguished by total heights and larger stems especially in the Sudanian zone. Termite mounds are or have been former habitats of many rodent species that transport and store forest seeds (Bationo et al., 2010a). Soil tillage improves the porosity of the soil, which promotes the infiltration of water, thus creating an edaphic microclimate favorable to the establishment and development of woody vegetation (Diallo, 2001; Bationo et al., 2001).

In all the forests surveyed, both in the Sudanian zone and in the Sahelian zone, the distribution of diameter and height classes of *P. erinaceus* is bell-shaped. Young individuals are poorly represented at all sites, even in protected areas such as Park W. This indicates that in addition to anthropogenic pressure, climate plays an essential role in the establishment and development of the species. The state of regeneration is however less critical in the Cassou forest with a shape parameter (c) 1 <c <3.6 compared to the other forests where c> 3.6 indicates stands with a predominance of elderly. However, the regeneration regime may have an impact on regeneration, especially late late-fires observed frequently in Park W. The same distribution of diameter classes was observed in the Burkina Faso part of Parc W by Nacoulma (2012), Glele et al. (2008) in the Wari Maro forest in Benin and on the central plateau in Togo (Adjonou et al., 2010). Yet some authors such as Camara (1997) and Ouédraogo et al. (2006) showed that the species has good germination capacity. The main constraint of *P. erinaceus* regeneration is the postabortion and development of juveniles into adulthood (Nacoulma, 2012; Bationo et al., 2001; Ouédraogo et al., 2006). The factors that are responsible of this lack of relay include herbivore pressure, vegetation fire and herbaceous competition. In addition, pruning and debarking for medicinal use are the main threats to *P. erinaceus* stands. In Tamou Wildlife Reserve 85% of individuals are totally or partially pruned. The untrimmed individuals are in tufts of *Acacia erythrocalyx*, a thorny vine that overcomes the tree crowns and renders them inaccessible to the shepherds. Repeated pruning of trees prevents fructification and therefore the production of seeds necessary for natural regeneration (Bationo et al., 2010b). *P. erinaceus* is the woody species which leaves are most sold as fodder in Bobo-Dioulasso in Burkina Faso (Sanou et al., 2011; Kiéma, 2007). Thus, the species that was dominant in the peri-urban forests of western Burkina Faso has either disappeared locally or has become rare (Fournier et al., 2001). These results show that *P. erinaceus* is threatened in the Sahelian zone and in the Sudanian zone.

Conclusion

Findings of the population structure of *P. erinaceus* according to the agro-ecological zones of Burkina Faso and Niger shows that the species is more adapted to Sudanian than Sahelian zones. *P. erinaceus* is threatened in its habitat, both in Sahelian and Sudanian zones due to anthropogenic pressure (late fire management, pruning for forage and debarking for various uses). All the distributions by class of diameter and height reveal a bell structure characteristic of the stands with predominance of elderly individuals. Small diameter individuals are virtually absent, posing a problem of species renewal in all long-term agro-ecological zones. Soil type and vegetation type control the growth rate of *P. erinaceus*. Indeed, the most vigorous individuals of the species were found on silty-clay soil, sandy loam soil and in the clear forests. The study also showed that mature individuals of this species remain only in the W Park, because of the integral protection measures that gave them a chance to reach the maximum of their growth but their regeneration is weak due to the occurrence of savannah management fire and the pressure of herbivores. National and international policies should be put in place for the rescue and conservation of residues of *P. erinaceus* stands that still exist as the species is critically endangered in all areas of this study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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