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Original Article

Living conditions and coping strategy of coastal communities contribute to the environmental integrity at the world heritage site of Dungonab Bay Mukkawar Island Marine National Park at the Sudanese Red Sea coast

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Abstract
World natural heritage sites (WNH) are those areas recognised for their unique natural resources and/or processes. The main objective of this study was to investigate the living conditions and diversity of livelihoods of coastal communities of the world natural heritage site of the Dungonab Bay-Mukkawar Island Marine National Park (DMNP-WNH). The fishing communities at Dungonab and Mohamed Gol villages were found to be deprived in water, electricity, education, health care, sanitation, flooring, cooking fuel and other livelihood assets. The expenditure of 82.9% of Dungonab and 91.2% of Mohamed Gol households exceeded their income. Accordingly, DMNP-WNH fishers were not able to invest in their livelihood assets and they used hook and line as the sole fishing gear. These conditions have restricted the access of respondents to fishing grounds. About 95% of Dungonab and 93.7% of Mohamed Gol respondents were experiencing extreme poverty. The quality of life at study sites was discouraging for human settlement, therefore, limiting the population growth and consequently the consumption of natural resources at DMNP-WNH. This has positively contributed to the environmental integrity. Access to clean water, electricity and diversification of fishermen livelihoods are of key importance to stimulate blue economy and sustain the environment of the DMNP-WNH.

Keywords: coastal communities; Dungonab; environmental integrity; living conditions; Red Sea; Sudan; world heritage

1 | INTRODUCTION

Areas inscribed as UNESCO world heritage sites (WHS) are of outstanding universal values (OUV) for present and future generations of humanity (Osipova *et al.* 2014). World natural heritage sites (WNH) are those areas recognised for their unique natural resources and/or processes that are often managed with the highest possible standards (UNESCO 2012).

The role of heritage as a driver of sustainable development in WHS has been emphasised since 2002 in Budapest Declaration (Conradin and Wiesmann 2014) and has widely been acknowledged (Baycan and Girard 2011; UNCSD 2012). The OUV is considered an economic asset capable of stimulating sustainable development activities, while at the same time its management and restoration activities may contribute to new employment opportunities (Zervaki 2016). Therefore, benefits of WNH sites may extend well beyond the spatial boundaries of the WNH

itself (Conradin and Hammer 2016) and well into the future. This is because WNH sites can attract sustainable economic activities of local and global impacts such as recreation and tourism (UNESCO 2012; Viñals and Morant 2012) which enhance human wellbeing of the local communities at these sites as well as the wider human society and concurrently conserve the natural assets of these sites. However, it has also been acknowledged that economic growth is not an immediate consequence of recognising a site as a WNH (UNESCO 2012; Cellini and Cuccia 2016). This is because the achievement of sustainable development in heritage sites is also governed by other factors such as governance, management plans, income and economic interests (Zervaki 2016; Din *et al.* 2017; Ripp and Rodwell 2017).

Sudan has four WHS, two cultural and terrestrial and two natural and marine. The natural world heritage site of Dungonab Bay Mukkawar Island Marine National Park (DMNP-WNH) located in the Sudanese Red Sea coast has an outstanding marine and coastal resources. These resources include an array of habitat types, such as extensive coral reef complexes and unique and healthy aggregations of the endangered species of dugongs and manta ray fish. The communities of DMNP-WNH are practicing small scale fishing (SSF) as the most affordable livelihood to sustain their living. They utilise different, yet limited, components of fishery resources including finfish, shellfish, and sea cucumber to improve their income.

Systematic research on the living conditions of DMNP-WNH communities is insufficient. Some surveys were undertaken on these aspects during and after the establishment of DMNP-WNH. For instance, an assessment of the coastal livelihoods available for DMNP-WNH communities was done by Harrison (2007). The study highlighted the limited land resources, the insufficient knowledge on marine resources, the weak financial and physical infrastructure and the need of management measures as the main obstacles to diverse livelihoods and to the wellbeing of DMNP-WNH communities at that time.

Recently, the demographic characteristics and the basic services and infrastructures at DMNP-WNH were surveyed (Persga 2016). The survey revealed that 79.7% of the DMNP-WNH males are artisanal fishers with remarkable level of illiteracy (49.9% illiterates), and little or no access to safe drinking water and health services. While the poverty of DMNP-WNH fishermen communities has not been explicitly stated, it has been implicitly indicated by the available literature (Harrison 2007; Harrison and Samoilys 2007; Persga 2013, 2016).

Considering the globally recognised status of DMNP-WNH, it is important to manage the poverty issues to ensure the successfulness of DMNP-WNH management and to maintain this status. This is because unfavourable living conditions could be one of the strongest driving forces behind natural ecosystems deterioration and over-exploitation of living marine resources particularly when fishing is the main source of income generation like the case of DMNP-WNH coastal communities. Under such circumstances fish harvesting would be escalated to meet the needs of livings and any management interventions would probably be prone to violation. Consequently, implementation of measures to improve living conditions, and reduce \ eradicate poverty are very essential to maintain the status of DMNP-WNH as an asset for humanity.

The main purpose of this study was to assess the level of poverty in the local communities of DMNP-WNH site at Dungonab and Mohamed Gol villages. Specifically, the study aimed to examine the living conditions and the diversity of the livelihoods of these communities and to relate these to status of the site as WNH. The second objective was to recommend relative and simple indicators for monitoring the improvements in living conditions of these communities as a result of management of DMNP-WNH. Thirdly, to investigate linkages between living standards and environmental integrity at DMNP-WNH.

2 | METHODOLOGY

2.1 Study area

The DMNP-WNH is located at the most north-eastern part of the Red Sea State (RSS) of Sudan in Gabait Elmadin locality. Climatically, it falls in the desert and semi-desert belt between latitude 20°28'N – 18°45'N and longitude 37°11'E – 38°10'E. The marine protected area (MPA) is close to the highway connecting RSS with Egypt. The population of the MPA has been estimated to be around 2500 people living in small and scattered settlements. However, two main villages are recognised as follows: Dungonab village and Mohamed Gol village. Dungonab village is located at the coast of the Dungonab Bay at about 176 km north of Port Sudan. The village population was estimated to be around 1200 natives of Beja tribe residing in 85 houses. The village is an important landing site for SSF which is the main livelihood of the community. Mohamed Gol village is located at about 10 km south of Dungonab and 166 km north of Port Sudan. The population of Mohamed Gol was estimated to be around 1300 individuals living in 100 houses. Mohamed Gol village is the base of all governmental offices of the locality. The major livelihood in Mohamed Gol is SSF with very few individuals working for the government.

2.2 Study methods

The following approaches were performed to assess the living conditions of the coastal fishing community at DMNP-WNH.

Semi-structured interview: Before developing the semi-structured interview, secondary data on the demographic characteristics, living conditions and poverty in Sudan was reviewed to identify the variables appropriate to explore

living conditions at DMNP-WNH. Then the guidelines of Abdrabo and Hassan (2003) and Bellu and Pansini (2009) were followed to produce the semi-structured interview. Subsequently, it was tested on small group at Dungonab before the survey. The semi-structured interview investigates the following characteristics of the fishermen: livelihoods, education, health care, sanitation, family size, monthly income, assets possessions (e.g. ownership or size of house, fishing gears, livestock, and home appliance), and expenditure on food, water, electricity, education, and healthcare. Every effort was made to make sure that the questions were easily understandable and answerable by the fishermen. In this regards some questions were framed with certain recall period and for some choices were provided.

Household surveys: Primary data was obtained through household surveys undertaken in January, April and July 2017 with the semi-structured interview. Due to the small population of the two villages and the relatively moderate number of the houses, it was decided to conduct a house to house survey. This was also because not all the villagers are full time residents at the villages as some individuals seasonally reside inland or are accustomed to temporarily movement or accustomed to temporarily move to the nearby villages or to the city of Port Sudan for different purposes such as to receive medical treatment, to visit relatives, or to shop for groceries.
Each village was virtually divided into 3 sections with reference to natural and \ or artificial features to facilitate conduction of the semi-structure interviews. The purpose of the interview was explained to the heads of the houses and those willing to participate in the survey were interviewed.

In Dungonab village, 40 households accepted to be interviewed from a total of 85 houses. The rest of the houses were either vacant (n = 12) or declined the interview (n = 33). In Mohamed Gol, 37 households of the 100 village houses accept to be interviewed. During the survey period the number of vacant houses in Mohamed Gol was 22 houses and those declined the interview were 41. The data obtained by the semi-structured interviews was analysed with the Statistical Package for Social Science (SPSS, version 16) and Excel (version 2010).

Transect walks: This was performed by walking through the village with a resource person from the local community to collect information on the natural environment of DMNP-WNH, services, infrastructures, livelihoods, and to identify other issues related to living conditions to complement those of the interview.

2.3 Data analysis

The living conditions indicators and their thresholds described in Santos and Alkire (2015) were compared with those prevailing at DMNP-WNH. For water, a household has access to clean drinking water if the water source is any of the following types: piped water, public tap, borehole or pump, protected well, protected spring or rainwater, and it is within a distance of 30 minutes' walk (round-trip). If it fails to satisfy these conditions, then the household was considered deprived in access to water. For improved sanitation, a household was considered to have access to improved sanitation if the household has some type of flush toilet or latrine, or ventilated improved pit or composting toilet, provided that they are not shared. If the household does not satisfy these conditions, then it is considered deprived in sanitation. For electricity: A household was considered to be deprived in electricity if it does not have access to it. For flooring, flooring material made of dirt, sand or dung counts as deprivation in flooring. For cooking fuel, a household was considered deprived in cooking fuel if the household cooks with dung, charcoal or wood. For assets, if a household does not own more than one radio, TV, telephone, bike, motorbike or refrigerator, and does not own a car or tractor then each person in it was considered deprived.

3 | RESULTS

3.1 Primary livelihood

The main primary livelihood and income source in both villages was fishing (Table 1) which practiced exclusively by men. Fishermen constitute 77.5% of Dungonab and 70.6% of Mohamed Gol communities. The second livelihood was petty trading which was practiced by 10% of the respondents in Dungonab and 5.9% in Mohamed Gol. In this survey only three salaried-employments were encountered. These were in education as teachers, in police, and in healthcare as midwifes.

TABLE 1 Primary livelihoods in DMNP-WNH communities of Dungonab (D; n = 40) and Mohamed Gol (MG, n = 37).

Livelihood	Percentage (%)		Employment type
	D	MG	
Fisher	77.5	70.6	Self
Petty trader	10	5.9	Self
Primary school teacher	5	0	Salaried
Midwife	2.5	2.9	Salaried
Traditional healer	2.5	0	Self
Firewood seller	2.5	2.9	Self
Police	0	2.9	Salaried
Sheepherder	0	2.9	Self
Others	0	11.9	-

However, the presence of the healthcare centre, the kindergarten, and the mosque that were run by the locality may indicate the presence of other salaried jobs. Nevertheless, only one person was employed in each of these institutions. In this survey the percentage of the salaried job in Dungonab (7.5%) and Mohamed Gol (5.8%) were

remarkably lower than the percentage of the self-employment jobs.

3.2 Secondary livelihoods

Most of DMNP-WNH respondents have no secondary income source (Table 2) and they relied on their primary livelihood for income. Almost all Mohamed Gol (97.1%) and Dungonab fishers (80%) had no alternative livelihoods to support their living. Notably, secondary livelihoods available for the fisher communities in DMNP-WNH site were also of self-employed type.

TABLE 2 Secondary livelihoods of DMNP-WNH communities in Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages.

Secondary livelihood (%)	D	MG	Employment type
No secondary occupation	80	97.1	-
Guard	7.5	0	Wage
Fisher	5	0	Self
Carpenter	2.5	0	Self
Camel keeper	2.5	0	Self
Daily worker	2.5	0	Self
Farmer	0	2.9	Self

3.3 Education

About 32.5% of Dungonab and 58.8% of Mohamed Gol local community were illiterate compared to 62.5% and 38.2% literate in Dungonab and Mohamed Gol respectively (Table 3). In both villages the majority attained primary school level of education which is subsidises by the government.

TABLE 3 Education in DMNP-WNH communities of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages.

Education (%)	D	MG
Illiterate	32.5	58.8
Khalwa	10	8.8
Primary school	40	23.5
Secondary school	7.5	5.9
University	5	0
No answer	5	2.9

3.4 Family working members

The majority of the households of DMNP-WNH (72.5% in Dungonab and 79.4% in Mohamed Gol) were dependent on one working member, usually the father (Table 4). Few families in both villages had more than one member to support their living (22.5% for Dungonab and 11.7% for Mohamed Gol).

3.5 House size and ownership

Most of the houses in DMNP-WNH were small in size with only two rooms (Table 5); one of the rooms was devoted for guests. Fortunately, almost all of the respondents (95%) in Dungonab village owned their homes. Those who lived in a rented house (2.5%) were mostly non-natives working with government such as in police. Exceptionally, very few members (2.5%) of the community owned two houses.

The respondents who owned houses in Mohamed Gol were 73.5% (Table 5). Mohamed Gol fishermen community had moved to a model village built by the government. The model village contained around 100 houses only. Therefore, some of the community members were living in rented houses.

TABLE 4 Number of working members \ family in DMNP-WNH communities of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages.

Family working members (%)	D	MG
One member	72.5	79.4
Two members	12.5	8.8
Three members	7.5	0
Four members	2.5	2.9
No working member	0	2.9
No answer	5	5.9

TABLE 5 House size and ownership among DMNP-WNH fishers of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages.

House size (%)	D	MG
One room	22.5	20.6
Two rooms	70	64.7
More than 2 rooms	7.5	11.8
No answer	0	2.9
House ownership (%)		
No house (rent)	2.5	26.5
One house	95	73.5
Two houses	2.5	0

3.6 Housing materials and flooring

The houses of Dungonab village were constructed from light materials and / or waste materials such as large plastic bags originally used for flour / sugar packing and cartoons used for packing of different goods (Table 6).

TABLE 6 House construction materials and flooring in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Type of house construction materials (%)	D	MG
Wood	95	14.7
Driftwood / plastic bags / sacks	2.5	0
Bricks, fiberglass	0	70.5
Sticks, cloth, cartoon	0	14.7
Missing	2.5	0
Flooring	0	70.5

In Mohamed Gol, 70.5% of the houses were built from bricks and fiberglass (Table 6). Families who did not

assign houses in the model village have built their own from wood / driftwood and other affordable materials. All house of Dungonab had no flooring at all, while in Mohamed Gol flooring existed only in houses built by the government (70.5%).

3.7 Sanitation

As indicated in Table (7) few of the fishermen of DMNP-WNH (30 to 35%) had pit latrines at home. Most of the community (70% of Dungonab community and 64.7% of Mohamed Gol) used shared pit latrines. Both shared and private pit latrines were without water supply. Comparatively, most households in both villages had a bathroom (Table 7), which was simply a confined corner of the house without a proper discharge system.

TABLE 7 Sanitation in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Sanitation (%)	**D**	**MG**
Private pit latrine	30	35.3
Shared pit latrine	70	64.7
Bath room	87.5	76.5
No bathroom	12.5	23.5

3.8 Private assets ownership

In Dungonab, 37.5% of the fishermen did not have a TV / satellite compared to 62.5% who did have such devices of small sizes (Table 8). In Mohamed Gol, households that did not own a TV and gas stove were 35.3% and 9.4% respectively compared to 91.2% who did not own a refrigerator (Table 8).

Most of Mohamed Gol community possessed a gas stove (90.6%) compared to 65% in Dungonab. Most of the fishing community in DMNP-WNH owned more goats (80% in Dungonab village and 52.9% in Mohamed Gol) than camels (10% in Dungonab and 11.8% in Mohamed Gol) (Table 8).

TABLE 8 Ownership of some assets in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Asset (%)	**D**	**MG**
TV	62.5	64.7
Refrigerator	10	8.8
Gas stove	65	90.6
Goats	80	50.9
Camel	25	11.8
Fishing boat	35	35.3
Hand lines	70	67.6

In both villages roughly about one third of the community owned a fishing boat (Table 8) while approximately over two thirds (62.5%) did not own a fishing boat. Comparatively, more fishermen possessed hand lines of varied sizes ranging from 70 mm to 120 mm accompanied with hooks of different sizes.

3.9 Social protection

The DMNP-WNH fishermen communities had received both financial as well as in kind social aid from the government and NGOs (Table 9). The Zakat Department and the Department of Social Welfare (RSS) provided financial support for some selected families in DMNP-WNH. The Department of Social Welfare provided small loans for interested households under a Revolving Fund Scheme to support micro-scale or family businesses.

TABLE 9 Social aid in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Donating agencies	**Receiving family** (%)	
	D	**MG**
Zakat Department	25	35.3
Department of Social Welfare	15	17.6
NGO	20	2.9
Bank loan	5	2.9

3.10 Access to water and electricity

The DMNP-WNH coastal fishing communities obtained their water from a desalination unit installed by the government but it was not connected to the villages. The desalinated water was sold in both villages by a vendor (Table 10). Dungonab fishing community had no access to public electricity (Table 10). However, about 57.5% of the respondents bought their electricity from owners of private diesel engines during the night hours only (6 to 11 pm). The remaining 42.5% had no access to electricity at all. In Mohamed Gol, the government provided the community with electricity on partial basis during the night hours (6 to 11 pm) with SDG 20 month^{-1} (1 SDG = 0.02 USD$; Table 10).

TABLE 10 Access to water and electricity in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Services	**Access (%)**	
	D	**MG**
Public water supply	0	0
water supply by vendor	100	100
Public electricity	0	81.1
Electricity by diesel engines	57.5	0
No electricity	42.5	17.6

3.11 Access to and expenditure on health and education

Coastal communities of DMNP-WNH site had no access to medical services at their place (Table 11). Only 10% of Dungonab households and 38.2% of Mohamed Gol indicated that they were on medical treatment that required regular spending (Table 11).

All fishers' households of DMNP-WNH had access to primary schooling (Table 11). Primary schooling was freely

available in the two villages of DMNP-WNH with one secondary school at Mohamed Gol.

TABLE 11 Access to and expenditure of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages on health and education.

Service	Access (%)		Expenditure (%)	
	D	MG	D	MG
Health	0	0	10	38.2
Primary Education	100	100	0	0

3.12 Household net available monthly income

Most of the households earned a monthly income around SDG 1750 as estimated by the fishermen (Table 12). Very few of them (10% in Dungonab and 7.5% in Mohamed Gol) earned greater than SDG 2250 month^{-1}.

TABLE 12 Household net available monthly income (SDG) in DMNP-WNH villages of Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37).

Net available monthly income (SDG)	Households (%)	
	D	MG
750	20	20.6
1250	27.5	20.6
1750	42.5	44.1
2250	0	2.9
2750	5	5.5
3750	5	0
No answer	0	6.3

1 SDG = 0.02 USD$

3.13 Monthly estimated expenditure

The expenditure of DMNP-WNH fishing community was divided into 2 broad components: (i) Food component which included meals, coffee and sugar; and (ii) Non-food component which included water, electricity, education and health (Table 13). The expenditure of the majority of the fishers in DMNP-WNH site (>80%) was greater than their income generated from fishing (Table 13). Only very few of the fishers (<20%) had an income greater than their expenditure.

TABLE 13 Average monthly expenditure of households in Dungonab (D; *n* = 40) and Mohamed Gol (MG; *n* = 37) villages.

Expenditure issues	Households (%)	
	D	MG
Food components	77.3	67.8
Nonfood components	12.3	7.13
Expenditure more than the income	82.9	91.2
Expenditure less than the income	17.1	8.8

4 | DISCUSSION

Most of the livelihoods available in DMNP-WNH were artisanal, subsistent in nature, and dependent on natural resources. This may reflect the status of economic activities and services available in DMNP-WNH site. While, almost all of these livelihoods were male-dominant, only one was practiced by women and men. This was petty trading which is practiced by women from inside their homes.

The communities of both Dungonab and Mohammed Gol were highly dependent on SSF as the major income-generating livelihood which was practiced exclusively by men. The restricted role of women in SSF in DMNP-WNH site, diverged from the worldwide recognition of women key role in production chain of SSF (Liontakis *et al.* 2020; Solano *et al.* 2021). This could largely be attributed to the short production chain as the catch is immediately sent to main market in the city without any post-harvest processing. A similar situation of male dominance in fisheries is reported from Bangladesh (Islam *et al.* 2013; Galib *et al.* 2016; Shalehin *et al.* 2022). High dependence on fishing perceived as a cause of poverty (Bene 2006) especially when other profitable economic activities were absent. This is the exact situation in DMNP villages, where SSF is the sole economic activity due to the lack of basic infrastructures and services which discourages any investment or urban development. Nevertheless, the site maintains significant opportunities for future sustainable blue economic activities such as tourism, aquaculture and shipping.

With regard to salaried and self-employed jobs, the situation in DMNP-WNH is in agreement with the situation of rural areas in Sudan, where 45% of the population are self-employed (NBHS 2009). However, in DMNP-WNH the difference between the salaried employment and self-employment was remarkable. This emphasizes the lack of services and infrastructures which greatly reduce economic growth opportunities. Higher incidence of poverty among self-employment segment of Sudan population (59%) was reported (NBHS 2009) compared to salaried employment segment (47%).

Similar to the pattern in primary livelihood, the secondary or the alternative livelihoods were all self-employments. Those who practiced fishing as a second employment, was the ones with salaried employment who go fishing on vacation.

Further, the livelihoods at DMNP-WNH were dependent on harvesting natural resources with conventional tools (e.g. fishing, farming and firewood collection). These kinds of livelihoods are economically limited with regard to income generation and require continuous extraction of the natural asset base to provide for food and other needs. Therefore, the diversification of livelihoods in DMNP-WNH is of key importance to the management of the MPA as well as to the community wellbeing. This situation entails scientific-based investment in human, physical, and financial capitals in order to improve the living standards, to sustain the natural assets, and to in-

vigorate the local economy at DMNP-WNH. Introduction of sustainable and job creating livelihoods such as community-based ecotourism and sea salt production is possible taking into consideration the status of DMNP-WNH as WHS.

The majority of the DMNP-WNH residents have attended primary school because primary schooling was free and was available at the villages. Dungonab residents' might tend to avoid unaffordable cost of attending secondary and university education outside their village. However, as it seemed that the community of the both villages had comparable proportion of secondary school graduates, it could also be true that people with better schooling might have moved out to the city for better employment opportunities. It was clear that illiteracy was remarkable in DMNP-WNH communities, and those educated were with low level of education which is considered to increase the likelihood of poverty and regarded as one of the social causes of poverty. High correlation was found between the level of schooling of population and the level of economic growth (Maiyo 2015; Mihai *et al.* 2015) because education enables individuals to acquire skills required for problem solving, critical thinking and high productivity. Specifically, fishermen with better schooling were found to show better adaptation to climate change in Malaysia (Abu Samah *et al.* 2019). Therefore, it is of key importance to include specific measures to introduce adult education and vocational training on fisheries as part of fisheries management and poverty eradication at DMNP-WNH or as a part of the overall management plan. According to the living standards threshold, 32.5% of Dungonab and 58.8% of Mohamed Gol households were deprived in education.

The number of family working member emphasised the scarcity of employment opportunities in DMNP-WNH. This finding is in agreement with the national employment rate which is only 68% for Sudan population (Ballon and Duclos 2015). This may tentatively reflect the dependency level within the families of DMNP-WNH when taken together with the dominance of self-employments, average family size of five members (Persga 2016) and the average monthly income discussed in the below paragraph.

The high rate of house ownership was largely due to the prevailing customary land use system which allowed members to freely select the location or the piece of land of their homes within the tribe territory. Comparative to the city of Port Sudan and unlike the case of rural areas in Sudan where the houses are spacious with large yard, most of the houses of DMNP-WNH are small in size (approximately 150 m^2) in spite of the availability of the land. This could be attributed to the unaffordable cost of house construction caused by the high price of the wood and the unavailability of carpenters in DMNP-WNH. Nevertheless, the possession of a house contributes significantly to reduction of living cost of the fishermen and tightens their relationship with the MPA.

Poor house construction materials were also reported for SSF communities from developing countries (Ahmed *et al.* 2013; Uddin *et al.* 2020). Poor housing conditions were associated with incidence of diseases caused by insects such as malaria (Snyman *et al.* 2015), dysentery, and eye infection.

During the transect walk and household visits, it was noticed that most of the households in DMNP-WNH have no flooring of any kind. This makes the whole village of Dungonab deprived in flooring. Innovative solutions to provide affordable house construction materials from local resources should be encourage as a measure to improve living conditions.

The high percentages of DMNP-WNH community members using shared pit latrines indicated the poor sanitation condition in the WNH site. Poor sanitation was reported for many coastal SSF communities (e.g. Asmal *et al.* 2019; Rahman *et al.* 2020). Sanitation, water supply and hygiene are interlinked. Poor sanitation and inadequate water supply accompanied with poor hygiene may lead to poor health by increasing the incidence of water-related diseases such as dysentery and skin infections. Sustainable water supply would improve sanitation practices such as containing biological waste from the immediate contact with human and disease vectors. Measures to help the community stay in healthy conditions such as improved sanitation, adequate water supply and awareness on hygienic behaviour should be considered a priority in planning for eradication of poverty and economic growth.

Private assets ownership is an indicator of welfare. Some private assets are essential component for good household functioning (e.g. refrigerator) and of environmentally friendly practices (e.g. gas stove). It is presumed that the availability of public services such as electricity, markets, and maintenance skills may have an influence on private assets ownership.

At present the TV / satellite is considered an essential tool of community development and entertainment particularly in rural areas like the DMNP-WNH. Interestingly, the status of TV ownership in DMNP-WNH was not in accord with the national one. On the national level, only 38.3% of Sudan population owned a TV (Ballon and Duclos 2015). The variation of home appliance ownership could be attributed to the affordability of the market prices of these goods with regard to the income of fishermen. Also, in the situation of DMNP-WNH site it is linked to the availability of services required to use these appliances.

Compared to the TV devices, refrigerators are more expensive and need constant supply of electricity to operate efficiently. In Dungonab, the lack of electricity in addition to the cost of transportation of goods from Port

Sudan markets to DMNP-WNH was not in favour of refrigerator ownership.

Similarly, use of gas stove instead of charcoal is linked to availability of gas supply. The availability of gas supply service in Mohamed GoI seemed to encourage the community to use this type of cooking fuel. However, in Dungonab, though the majority of the fishermen households (65%) did own a gas stove, but they used charcoal due to absence of gas supply. The nearest sale point was in Mohamed GoI village. Therefore, the price of gas in DMNP-WNH was higher compared to Port Sudan because it included the cost of transportation that makes it unaffordable to the most of the community.

Charcoal and firewood were the most utilised types of cooking fuel in DMNP-WNH. Reliance on these kinds of fuel pressurised the natural desert vegetation around DMNP-WNH. In particular, Acacia trees are the main source of charcoal making. However, in the customary law of the Beja tribes (known as silif) cutting of live trees is prohibited and it equate to killing a human. Outsiders who are regularly encountered leaving DMNP-WNH with their loads do most of tree cutting for charcoal making. Preventive measures should be imposed on charcoal and investment in sustainable energy should be encouraged.

Goat seemed to be the major domestic animal in DMNP-WNH compared to camels. They were donated to some families in DMNP-WNH over the past years as a social aid. Also, the market price of goat was relatively affordable than the market price of camels and it is easier to take care of goat at home especially by women. Goats and camels are very important for food security in DMNP-WNH as a source of milk, which is one of the daily consumed food items for the residents of these remote villages as well as the visitors. Therefore, selling fresh milk, in particular camel milk, has become one of cash sources for some of DMNP-WNH residents who keep these livestock. Nevertheless, and in extreme conditions these livestock may serve as a source of cash and food. Rearing of animals by fishers of DMNP-WNH, particularly goats, is one of the coping strategies of the community to maintain food security and to provide liquid money for urgent and unexpected needs.

The people of DMNP-WNH were Beja natives who were historically pastoralists and due to the recurrent drought spills and famines from the 1940s to the 1980s, they lost their livestock and some of them changed their livelihood to fishing as in DMNP-WNH community. However, livestock keeping remains of remarkable financial and social significance in the Beja culture, and many individuals strive to restock by reinvesting savings into livestock. The fishermen consider livestock raising as an alternative livelihood strategy to achieve food security and to earn some cash by selling the milk produced by the animals. However, the scarcity of both water and rangeland increases the expenses of raising livestock and limit the number of animals that a household can maintain.

Since by now the community of DMNP-WNH has moved to become a coastal fishing community, the possession of fishing gears is essential for their livelihood and eventually for their wellbeing. The major type of fishing boat in DMNP-WNH is known locally as Houri, it is either a fiberglass or wooden boat, 6 to 9 m in length, equipped with an outboard engine (15 to 45 hp). Unlike the majority of other small scale and artisanal fishing communities, fishing in DMNP-WNH was practice solely with hook and lines.

These fishing gears determine the fishing effort exerted by DMNP-WNH fishermen in particular with regard to target species, fishing grounds, distance travelled, duration of fishing trip, fish storage capacity, and number of fishers per boat. Accordingly, DMNP-WNH fishers could only target certain kinds of fisheries which are mainly coral reef, pelagic and demersal fisheries.

Hooks and lines are inexpensive and sustainable gear of fishing compared to nets, traps, and wounding gears (Rouxel 2017; Anuja *et al.* 2018). This is because very limited number of fishes can be captured per line and in DMNP-WNH site all fish caught are totally consumed. Further, the fishing effort of these communities is controlled by weather conditions and seasonal availability of fish.

To cope with weather conditions two types of fishing trips were practiced by fishers of DMNP-WNH. The first is a daily fishing trip inside Dungonab Bay locally known as Faka or Tashrega, which is sometimes undertaken during unfavourable weather conditions such as during strong winds, rainfall, and very hot temperatures times. The second one is commonly one week long (6 – 7 days) fishing trip locally known as Ezba usually performed during abundant fish season and prevalence of favourable weather conditions. In this kind of trip, fishermen (3 – 4 fishers per fishing boat) have to secure their food, fuel, and ice to preserve the fish catch for the duration of the trip. The cost of these is not affordable for most of the fishermen. A fish trader supplies the fishing trip`s needs and buy the catch at the end of the trip. Therefore, the fish selling price at the landing site is principally determined by fish traders rather than by the fishermen themselves who receive one third of the total value of the fish catch according to a customary agreement.

Consequently, the fishing pattern of the fishermen in DMNP-WNH site seemed to be in accord with the prevailing natural conditions and the coastal resources of the MPA, therefore, it might contribute to its environmental integrity taking into account that other external factors are stable.

Against this background DMNP-WNH fishermen are not able to control their principal livelihood due to financial, physical, and natural (unfavourable weather conditions / resource biological limitation) constrains. This has

some implications on the income generated from fishing and consequently on the living conditions and poverty of DMNP-WNH fishermen. Financial constrains may include inability to finance fishing trips, restricted access to bank loans, and the inability to save for acquiring required fishing gears. Physical constrain are those relevant to availability of pre- and post-harvest services such as well-equipped fishing boats, landing sites prepared with storage facility, and transportation of catch to major markets. The small size and the light materials of the Houri boats pose significant safety concerns during conditions of strong wind, high waves, and torrential rains to the extent of preclusion of fishing trips and subsequent loss of income. Consequently, the earning of DMNP-WNH fishermen is extremely irregular and low trapping most of them in perpetual cycle of debts. Governmental subsidies to the fishermen, empowerment of fishermen organization, and investment in infrastructures related to fisheries would help to enhance the situation of fisheries livelihood as well as the fishermen.

Although the distribution of social aid / zakat to the community of DMNP-WNH was based on official assessment of poverty in local communities it seemed to be of little benefits. This is because the type of aid provided was not based on systematic investigation on the capacities of the families and the prevailing natural environment. In-kind aids such as goats required fodder, water, and veterinary care to be productive. In the light of water scarcity and the desert environment at DMNP-WNH raising livestock may place a burden on the families by increasing their water consumption and the expenses incurred to buy fodder. Better social assistant could be achieved if both governmental and NGOs moved towards provision of basic community needs and services such as water supply, health care, electricity, and transportation.

Additionally, it was clear that donor agencies with greater financial impacts such as banks and micro-finance companies were absent in DMNP-WNH. Indeed, loans were only affordable to those with stable monthly income from salaried job employment which is not the case of fishers at DMNP-WNH. Special loaning policy targeting SSF sector is urgently needed to be develop to meet the financial condition of the fishers in order to help them maintaining their livelihood.

Water resources in DMNP-WNH were very scarce due to the overall climate variability of the region that solely depended on torrential rainfalls and flash floods. Such regions were described as of low water security level (Grey and Sadoff 2007). Nevertheless, an unsustainable water technology is used to provide water supply to the community. The desalination of ground water in DMNP-WNH as the sole technology of water provision without any other accompanied water harvesting techniques is unsustainable. Community water services, in particular water supply is a crucial key to sustainable development (Katko and Hukka 2005; Anik *et al.* 2016).

The vendor supplied the water with a tanker and uses the jerry can as a measurement and pricing unit. These further worsen the water insecurity in DMNP-WNH especially when the desalination unit and the tanker are in need of maintenance. The way of water supply incurs further costs on the community due to the inclusion of fuel cost in the price for those located at a distance from the source (in Mohamed Gol). Monthly expenditure on water for Dungonab fishers varied between SDG 80 to SDG 270 with an average of SDG 59.23. The DMNP-WNH communities pay high prices for small quantities of water, which of course increases their living expenses. Additionally, the way the water is handled and stored in DMNP-WNH, increases the chance of its contamination with dirt and pathogens which jeopardise the health of the community.

The duration of electricity and the quality of the electric current were not suitable to help in ice production required for storage of fish during the fishing trip or to preserve the harvest after the trip. Lack of secured supply of water and electricity greatly influenced the socioeconomic conditions of DMNP-WNH communities. The inadequate qualities of these services have bearings on fishing, household expenditure, education, sanitation, health, communication, livestock and economic growth opportunities in general. For instance, scarcity of water limits community chances to raise livestock and to practice conventional farming which otherwise could have helped to diversify livelihood opportunities and generate additional income. Future, poverty alleviation policies should take into account the linkages between water and other dimensions of living conditions such as health, education and waste disposal. At the core of these policies measures on sustainable harvest and management of available water resources in the MPA should be developed and implemented. Provision of sustainable water supply and electricity are at the top of the indicators to monitor the living conditions in DMNP-WNH.

The healthcare centres in villages of DMNP-WNH were understaffed and ill-equipped; those who need medical treatment had to go to the city. Sudanese households spent 17% of their income on health. This could be due to the wide coverage of the services of governmental health insurance that provides treatments with one 1\4 of the original cost. In Sudan, the average expenditure on education is 6% of the total household income since primary and secondary education is mostly public. However, fishermen communities may need specific type of formal or informal training oriented towards their livelihood. Technical training on fishing gears repair and maintenance and training on relevant topics of business management could possibly enhance their indigenous knowledge on the biological assets and lead to a better performance.

The net monthly income of the household in DMNP-WNH varied among fishermen as well as with fishing season which was controlled by the weather conditions and availability of species of fish. A similar case was reported in other studies (Peixer and Neto 2020; Kapembwa *et al.* 2021). Variation of the income among fishers of DMNP-WNH could be attributed to variation in fishing gears ownership (boat and hook and line) between fishers and the number of fishing trips made. Fishers who own boats are in better off condition and they employ those who do not own boats with them.

The minimum estimation of the net available income of the fishermen of DMNP-WNH (SDG 750) was higher than the minimum wage in Sudan (SDG 425 for 40 hours week^{-1} in November 2017). This is in accord with the general trend of SSF income. Income from fishing was often found to be higher than the national average income (Bene *et al.* 2010). However, the apparent level of poverty recorded worldwide in SSF is often more closely related to the severe degree of geographical and / or political isolation that characterises many full-time fishing or mixed fishing–farming communities which is typically the case of DMNP-WNH. As mentioned earlier, the remoteness of DMNP-WNH elevate the overall cost of living because of the extra cost of services and commodities caused by transportation.

When the monthly income of DMNP-WNH fishermen was compared with the World Bank's standard of poverty measurement based on income level of USD$ 1.90 a day and based on official exchange rate of Sudanese currency (1 USD$ = SDG 55 in 2017), about 95% of Dungonab and 93.7% of Mohamed Gol communities were living in extreme poverty conditions. Further, this is also confirmed by the national poverty line for rural areas set at SDG 4044 based on monthly household consumption (AFDB 2018).

The distribution of the income generated from the SSF sector of DMNP-WNH showed a contrasting disparity throughout the production chain. While the fishers of DMNP-WNH at the bottom of production chain continued to live in persistent poverty, fish traders at the top of the production chain were by far well-off. As indicated earlier the income generated from a single fishing trip is divided into three thirds as follows: one third for the fishers, one third for the fish traders, and one third for the trip preparation including fuel, ice, food and other expenses. Sometimes the trip income is not enough to meet these expenses and the fishers may end up in debt. The most important issue here is that the selling price of the fish at the landing site is determined by the fish traders. This price is by far lower than the price at the fish market in town. In this way, fish traders earned more profit and became wealthier than the fishermen. This is in agreement with other researchers (Purcell *et al.* 2017; Peixer and Neto 2020) who found that fish traders have the highest income compared to fishermen and other categories in the fish production chain.

The fish production chain in DMNP-WNH fishing communities was remarkably short consisting of the two following categories: fishermen-fish traders. The fish trader transports the catch to retailers and consumers in the city where all post-harvest processes are undertaken. Further, value chain analysis would greatly help to addresses response strategies that enhance the sustainability and competitiveness of SSF of DMNP-WNH.

Household expenditure was taken as an indicator of availability of welfare services. The pattern of expenditure of DMNP-WNH was in conformity with the national pattern of expenditure reported in Ballon and Duclos (2015) where 61% of Sudanese income is spent on food and was in conformity with Alam (2004) who reported that the fishermen of Bangladesh expend most of their income (85%) on food. Most of the non-food expenditure was reported to be on water.

When the income of DMNP-WNH fishermen was compared to their expenditure on some food and non-food items, the expenditure was greater than the income for 82% of Dungonab and 91.2% of Mohamed Gol fishermen. This is in accord with the findings on income poverty in the previous paragraph and it confirms the verbal statement made by the fishermen about their debt cycle.

The relationship between poverty and environmental integrity has been in a continued debate and investigation at many levels (Scott 2006; World Bank 2008). The consensus was that poverty is a driving cause of environmental degradation that hinder sustainable development (Duraiappah 1996; Omoboye 2011). However, the case DMNP-WNH site offer a divergent example where the multidimensional poverty limits the density of the population and this restricts the exploitation of the natural resources of the MPA. In addition to, some customary rules and indigenous knowledge are also influential in controlling use of coastal resources in DMNP-WNH. These customary rules would be very valuable if included in the management plan of DMNP-WNH site and would receive high recognition by the communities. This supported by the high respect of other social customary rules such as those on reconciliation and conflict resolution.

5 | CONCLUSIONS

The communities in DMNP-WNH are deprived in several dimensions of the welfare of an individual to the limit that they are not able to control their own livelihood. Outsiders play significant role in organising the fishery livelihoods in DMNP-WNH by fully financing pre- and post-harvest activities. Therefore, the multidimensional poverty of DMNP-WNH fishers is largely due to some economic and social factors such as absence of services (e.g. electricity, water, transportation and bank loans), accessibility to market, and absence of active and strong

fishers' organisation that if in place would enable fishermen to become independent and control their own livelihood. Inadequacy of water supply is a major hindrance to broaden the economic base in DMNP-WNH and to alleviate poverty. Therefore, availability of sustainable water supply is recommended as an indicator of future positive changes in the living standards in DMNP-WNH. It could be concluded that the quality of life at DMNP-WNH seem to be discouraging for human settlement, therefore, limiting the population and eventually the consumption of natural resources at DMNP-WNH which has positively contributed to the environmental integrity of the DMNP-WNH leading to its recognition as a WNH site. Also, the present living conditions allow for greater opportunities of sustainable blue economic growth that may maintain the WNH status.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

NAO designed the study. NAO and EAAI performed the survey and analysed the data. NAO drafted the manuscript with input from EAAI.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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