


Research Article

# Bone Marrow Examination Findings Among Sudanese Patients During the Sudanese Armed Conflict (April 2023 to February 2025)

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## Abstract

**Background:** Armed conflict in Sudan has severely disrupted healthcare delivery, and access to diagnostic services. Despite the increasing burden of hematological disorders, data on bone marrow examination (BME) findings in such settings remain limited. This study aimed to characterize the spectrum of BME diagnoses in Sudanese patients during a period of ongoing conflict. **Methods:** A retrospective cross-sectional study was conducted at Al-Mek Nimer University Hospital, including 291 patients who underwent bone marrow examination (aspiration and trephine biopsy) between April 2023 and February 2025. Data were analyzed using SPSS. **Results:** Hematological malignancies accounting for 64.6% of cases. Leukemia was the most common diagnosis (38.8%), particularly chronic lymphocytic leukemia (17.2%), acute lymphoblastic leukemia (11.7%), and chronic myeloid leukemia (10.3%). Non-malignant conditions represented 35.4% of cases, mainly reactive marrow changes (17.5%) and megaloblastic anemia (7.2%) being the most frequent. Most patients were aged 41–60 years (29.9%), with a slight male predominance (52.9%). Geographically, most cases originated from River Nile State (52.9%) and Khartoum State (33%). A notable proportion of patients were unemployed (58.8%), suggesting socioeconomic vulnerability. **Conclusion:** There is high burden of advanced hematological malignancies and reactive marrow patterns likely due to delayed access to care during conflict. Bone marrow examination remains essential diagnostic tool in resource-limited settings. Strengthening mobile diagnostic services, promoting early screening among high-risk groups—particularly the elderly and unemployed—and implementing micronutrient supplementation programs may help reduce morbidity and improve outcomes in conflict-affected populations.

## Keywords

Bone Marrow Examination, Hematological Malignancies, Reactive Marrow Conflict Settings, Sudan

## 1. Introduction

Bone marrow located within the inner fixed confines of bone and is the primary hematopoietic organ responsible for

the production of the blood cellular elements that perform vital functions of oxygen transport, protection against bacterial and viral pathogens, control of inflammatory responses, and

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participation in endothelial repair as well as clot formation [1].

Examination of the bone marrow is one of the most valuable diagnostic tests used to evaluate hematological disorders. Bone marrow aspiration and biopsy is also used to stage lymph proliferative disorders and for prognostic purposes in chronic lymph proliferative disorders such as chronic lymphocytic leukemia [2].

Bone marrow aspiration and biopsy is also useful in the diagnostic workup of fever of unknown origin. It may reveal infections, such as tuberculosis mycobacterium avium-intracellulare infections histoplasmosis, leishmaniasis, and other disseminated fungal infections. It may be useful in establishing the diagnosis of storage diseases and diagnosing metastatic non-haemopoietic malignancies that have spread to the bone marrow when all other imaging and diagnostic modalities have failed or when a leucoerythroblastic peripheral blood picture is present [3].

The importance of bone marrow examination in any hematological disorder cannot be overemphasized. In its absence the investigation of any hematopoietic disorder, unless otherwise well defined, documented and prognostic ally evaluated, is incomplete. Even in many cases where the diagnosis is clinically and pathologically established an examination of the bone marrow remains an integral part of the practice of effective, scientific [4].

Bone marrow examination (aspiration and/or biopsy) is an essential procedure in clinical hematology, widely indicated for the diagnosis, staging, and monitoring of various systemic and hematologic conditions. Bone marrow examination remains a cornerstone in the diagnostic workup of hematologic and systemic diseases. Its value lies not only in diagnosis but also in prognosis, staging, and monitoring response to therapy.

## 2. Problem Statement

The burden of hematological disorders is rising in conflict-affected regions; there remains a critical lack of published data on bone marrow examination (BME) findings in Sudan, particularly within the Shendi region. The ongoing armed conflict has significantly disrupted healthcare services, delayed diagnostic evaluations, and may have contributed to late-stage disease presentation among patients evidence-base decisions sand hinders effective national health planning. Consequently, a comprehensive investigation of BME patterns is essential to enhance diagnostic accuracy, support clinical decision-making, and guide targeted humanitarian responses in unstable settings.

## 3. Justification of the Study

Armed conflict in Sudan has significantly disrupted healthcare systems, leading to delayed diagnosis, limited access to specialized investigations, and worsening outcomes for

patients with hematological disorders. Bone marrow examination (BME) remains a cornerstone diagnostic tool for a wide range of malignant and non-malignant hematological conditions. However, there is a scarcity of local data describing the spectrum and frequency of bone marrow findings in Sudan, particularly during periods of instability. Generating such data is essential to understand disease patterns, identify high-risk populations, guide resource allocation, and support the development of targeted diagnostic and therapeutic strategies in resource-limited and conflict-affected settings.

## 4. Objectives

### General Objective

To evaluate the pattern and distribution of bone marrow examination findings among Sudanese patients at Al-Mek Nimer University Hospital during the period April 2023 to February 2025.

### Specific Objectives

- 1) To determine the frequency of hematological malignancies diagnosed by BME.
- 2) To identify the common types of leukemia and other malignancies.
- 3) To assess the prevalence of non-malignant bone marrow conditions.
- 4) To analyze the demographic characteristics (age, gender) of patients undergoing BME.
- 5) To describe the geographic distribution of cases.
- 6) To explore the association between socioeconomic status (e.g., employment) and disease patterns.

## 5. Previous Study

### 1-Findings in Sudan:

Within Sudan, data on BME patterns is limited but provides essential baseline information. Elmadhoun et al. (2015) conducted a pivotal study in Atbara, North Sudan, reviewing 112 bone marrow aspiration (BMA) cases over six years. [5] The primary indications were pancytopenia (38.4%), unexplained anemia (34.8%), and suspected leukemia (11.6%). Crucially, the diagnostic yield was high (76.8%), with aplastic anemia identified as the most common pathological finding. [5] This study underscores the diagnostic value of BMA in Northern Sudan for evaluating cytopenias and suspected hematological malignancies.

### 2-Findings in Africa:

Studies across Africa demonstrate consistent patterns in BME indications and diagnoses, often reflecting regional burdens of infectious disease, nutritional deficiencies, and resource constraints:

#### 1-Indications:

Anemia and pancytopenia are consistently dominant reasons for BME across the continent. Studies in Nigeria (recurrent anemia 32.2%, presumptive leukemia 27.7%), [6] Kenya

(anemia predominant), [2] Malawi [2] and South Africa (suspected malignancies 67%) [7] confirm this trend. Fever of Unknown Origin (FUO) is another significant indication; Hot et al. (2009) found BME had a 23.7% diagnostic yield in immunocompetent FUO patients, primarily identifying hematological malignancies like lymphoma. Anemia and thrombocytopenia were predictive of a positive yield. [7]

### 2-Diagnostic Findings: Non-Malignant Disorders:

Nutritional deficiencies, particularly megaloblastic anemia and combined deficiencies are highly prevalent. They were the most frequent diagnoses in Northeastern Nigeria (20.3% megaloblastic, 9.9% combined deficiency) [8] and common findings in Kenya (nutritional anemias, especially megaloblastic). [2] In Northeast Ethiopia, non-malignant disorders (57%) like erythroid hyperplasia, aplastic anemia, and combined deficiency anemias significantly outnumbered malignancies. [8] Reactive or benign changes constituted 60% of diagnoses in Malawi. [9]

### Malignant Disorders:

Leukemias (Acute Lymphoblastic Leukemia-ALL, Acute Myeloid Leukemia-AML), multiple myeloma (MM), and lymphomas are consistently reported. In South Africa (Kwa-Zulu-Natal), leukemia 20%, MM (13%), and lymphoma (11%) were leading diagnoses. [10] In Kenya (Aga Khan, Nairobi), AML was the most frequent malignant disorder. [3] Pediatric studies in Kenya found malignancies (27%), predominantly ALL, in a quarter of examinations. [11] South African research confirmed the high utility of BME for detecting bone marrow involvement in lymphoma (43.6% NHL, 35.7% HL). [12]

In Ethiopia, malignancies like CML, AML, CLL, MM, and ALL constituted 11.4% of confirmed hematological disorders. [12] A Saudi Arabian audit noted acute leukemia as a common diagnosis in patients with pancytopenia undergoing BME. [13]

### 3-Diagnostic Yield:

BME demonstrates high diagnostic utility across Africa. Yields of 76.8% in Sudan, [5] significant diagnostic information in South Africa, [10] and 23.7% specifically for FUO [7] highlight its value. In Iran, BME had the highest yield for suspected leukemia (54%) and MM (30.3%). [2]

### 3-Global studies:

Global studies reinforce the critical role of BME while highlighting specific diagnostic patterns and challenges:

#### A-Hematological Malignancies:

Studies confirm BME's indispensability for diagnosing and classifying leukemias, myelodysplastic syndromes, myeloproliferative neoplasms, myelomas, and lymphomas. In Uttarakhand, India, leukemia (58%), MM (24.7%), and lymphoma (14.8%) were the predominant hematological malignancies diagnosed via BME, showing age peaks in adolescents/young adults (11-20 years) and older adults (51-60 years), with a male predominance (2.3: 1 ratio). [14]

#### B-Specific Diagnostic Scenarios:

Fever of unknown origin: As noted in the African context,

BME remains valuable globally in FUO, particularly when hematological abnormalities like cytopenias are present. [7]

Isolated Thrombocytopenia: The necessity of routine BME for diagnosing Immune Thrombocytopenic Purpura (ITP) is debated. Jubelirer and Harpold (2002) reviewed studies suggesting BME may not be essential for typical ITP, as findings are often consistent and alternative diagnoses rarely emerge during follow-up. [15]

Genetic Susceptibility: Research extends beyond morphology to genetic factors. Elderberry et al. (2023) identified a significant association between the GSTT1 null genotype and increased susceptibility to Philadelphia-negative Chronic Myeloid Leukemia (Ph-ve CML), highlighting the role of detoxification enzyme polymorphisms in hematological malignancies. [16]

#### C-Unusual Presentations & Complications:

Case report illustrates rare but critical findings detectable by BME correlated to underlying conditions/therapies:

- 1) Chronic Myeloid Leukemia (CML) presenting with spontaneous splenic rupture [17]
- 2) CML complications like sudden bilateral deafness (potentially hyper leukocytosis-related) and hydroxyurea-induced leg ulcers [18]
- 3) Disseminated mucormycosis causing paralysis post-BM Tin AML. [19]
- 4) Rare primary bone marrow lymphomas mimicking aplastic anemia. [20]
- 5) Asymptomatic bone and bone marrow metastases from gastric signet-ring cell carcinoma. [21]

#### D-Diagnostic Utility:

Globally, BME maintains its status as a definitive test when peripheral blood and routine labs are inconclusive, guiding management and prognosis, especially where advanced diagnostics are limited. [8, 14]

## 6. Methodology

### 6.1. Study Design

This is a retrospective, Descriptive, cross sectional, hospital based study conducted to assess bone marrow examination finding at Al-Mek Nimir University Hospital in Shendi Sudan.

### 6.2. Study Area

Shendi town: This study was done in Shendi city, which located in the north of the Sudan. It situated on eastern bank of the Nile River, approximately 150 km northeast of Khartoum. The city covers an area approximately 124000 km squares population estimated between 1787 and 2211. The main tribes living in Shendi are Jaalya, Shwaygia, Hasania and other group. Most of population are Farming. There are several general centers for different service and also there is Shendi University with different colleges. There are many health care and hospital and oncology centre for cancer treatment which is

third hospital for oncology in the Sudan.

Al-Mek Nimir University Hospital; which is established in July 2002, is one of the largest hospitals in the area which have different departments and provide good health services for the population in the Shendi area. There is a medicine department, surgery, pediatric, obstetrical, ENT, ICU, ophthalmic, dental unit, minor and major theater, CCU, emergency room, oncology and dialysis unit, there is also a blood bank and pharmacy and laboratory.

### 6.3. Study Population

All patients who underwent bone marrow examination during the study period were included.

### 6.4. Sampling Technique

The population selected by simple random sample.

### 6.5. Sampling Size

The total sample size was 292 patients.

### 6.6. Inclusion and Exclusion Criteria

Inclusion Criteria

- 1) All patients who underwent bone marrow aspiration and/or trephine biopsy at Al-Mek Nimir University Hospital.
- 2) Patients of all age groups and both genders
- 3) Records with complete diagnostic and demographic data
- 4) Cases performed between April 2023 and February 2025.
- 5) Exclusion Criteria
- 6) Incomplete or missing patient records
- 7) Poor-quality or inadequate bone marrow samples
- 8) Repeat bone marrow examinations for the same patient (only the first diagnostic sample included).
- 9) Cases with inconclusive or non-diagnostic results

### 6.7. Data Collection Tools

Data were collected from patient's files available at the hospital.

### 6.8. Data Analysis

Data was analyzed by SPSS and presented in figures and tables.

### 6.9. Ethical Consideration

Ethical approval was obtained from the Department of Community Medicine, Faculty of Medicine, Shendi University. Permission was obtained from hospital administration.

## 7. Results

A total number of 291 bone marrow examination findings in Al-Mek Nimir University Hospital were enrolled in this study during the period from April 2023 to February 2025, the data obtained are explained in tables and figures.

The youngest patient was a 2-month-old female diagnosed with Gaucher disease, while the oldest was a 104-year-old female with megaloblastic anemia.

According to the age:

Out of a total of 291 patients with age distribution ranging from less than 1 year to over 75 years, the estimated mean age was approximately 41.5 years, with an age range of 2 months to 104 years and an estimated standard deviation of 22.9 years, indicating significant age variability within the sample. The largest age group was 41–60 years (29.90%), followed by 61–75 years (22.68%) and 19–40 years (19.59%). The smallest age category was infants under 1 year (1.37%). This distribution reflects a predominantly middle-aged and older adult population. (Table 1, Figure 1)

According to the gender:

One hundred and thirty-four were male (52.92%) and 137 were female (47.08%) the male to female ratio was approximately 1.1: 1 with the largest gender disparity in the 61–75 years group indicating a slight male predominance. (Figure 2)

According to the residence:

The majority of individuals' residence in River Nile State (52.9%) and Khartoum State (33%), with other regions each representing less than 10% of the sample (Figure 3)

According to the Occupational:

Occupationally, 58.8% report housewife, followed by freelancer work (13.1%) and farmers (12.0%). Other occupations, such as driver (5.2%) and police (3.1%), are less common, with highly specialized roles like technical radiation and trader being rare (0.3% each). (Table 2, Figure 4)

According to the investigation type:

All 291 individuals underwent aspiration and biopsy. (Figure 5)

According to the finding:

The most prevalent results were reactive bone marrow (17.5%) and chronic lymphocytic leukemia (17.2%), followed by ALL (11.7%), multiple myeloma (9.6%), and megaloblastic anemia (8.2%). Rare conditions included thalassemia and hairy cell leukemia (0.3% each). The diverse diagnoses, with a significant proportion of reactive bone marrow and leukemias, suggest a population with varied hematological disorders, predominantly non-malignant or chronic conditions. (Figure 6)

Diagnosis results and AGE Cross tabulation:

Diagnosis results and AGE Cross tabulation Leukemia (113 cases) and non-specific/reactive conditions (53 cases) are the most frequent diagnoses, with leukemia distributed across all age groups, peaking in middle-aged (32) and elderly (30) individuals. Anemia (35) is more common in elderly (13), while lymphomas (15) and myeloma-related disorders (31) are rare

in pediatric cases. The chi-square test ( $\chi^2 = 256.805$ ,  $df = 120$ ,  $p < .001$ ) suggests a significant association between age and diagnosis, indicating age influences hematological conditions. (Table 3)

Diagnosis results and Residence Cross tabulation:

Diagnosis results and Residence Cross tabulation Leukemias (113 cases) and non-specific/reactive conditions (56 cases) dominate, with Nile River showing the highest frequency (63 and 34 cases, respectively), followed by Khartoum State (42 and 15). Anemias (35) and myeloma-related disorders (31) are also notable, particularly in Nile River (19 and 24). Other regions have low case counts, with no dominant diagnosis. The chi-square test ( $\chi^2 = 281.496$ ,  $df = 160$ ,  $p < .001$ ) suggests a significant association between residence and diagnosis, but the high proportion of cells with expected counts below 5 (91.5%) limits reliability. The data indicates regional variations, with Nile River and Khartoum State bearing the majority of hematological cases, particularly leukemias and reactive conditions. (Table 4)

Distribution of Bone Marrow Diagnosis in Shendi and around:

Distribution of Bone Marrow Diagnosis in Shendi and around Shendi shows the majority of cases coming from Shendi and Hager Alasel. Leukemias were the most commonly reported group of diagnoses, accounting for 51 out of 135 cases (approximately 38%), with a notably high concentration in Shendi. Other common diagnoses included anemias (17 cases) and myeloma-related disorders (20 cases). Meanwhile, rare conditions such as Gaucher disease, histiocytic disorders, and bone marrow fibrosis were reported in only one or two patients. (Table 5)

Diagnosis results and Occupation Cross tabulation:

Leukemias (113 cases) and non-specific/reactive conditions (57 cases) are the most common diagnoses, predominantly among the unemployed (77 and 36 cases, respectively). Skilled laborers also show notable frequencies for leukemias (29) and non-specific/reactive conditions (19), while professionals have fewer cases across all diagnoses (e.g., 7 for leukemias). Anemias (35) and myeloma-related disorders (31) are less frequent but still significant among the unemployed (22 and 14). The chi-square test ( $\chi^2 = 194.917$ ,  $df = 220$ ,  $p = .887$ ) indicates no significant association between occupation and diagnosis, likely due to the high proportion of cells with expected counts below 5 (94.8%), which undermines the test's

reliability. The data suggests hematological conditions are most prevalent among the unemployed, with skilled laborers also affected, but no clear occupational pattern emerges. (Table 6)

Bone Marrow Findings according to Underlying Cause:

Bone Marrow Findings by Underlying Cause among 61 cases, reactive bone marrow is the most prevalent finding (51 cases, 83.6%), predominantly associated with hypersplenism (25 cases, 41.0%) and immune-mediated peripheral destruction (9 cases, 14.8%). Secondary metastasis accounts for 5 cases (8.2%), with 4 linked to reactive marrow and 1 to hypoplastic marrow. No specific pathology was observed in 5 cases (8.2%), mainly tied to excluding multiple myeloma (4 cases). Hypoplastic bone marrow (3 cases, 4.9%) is rare, linked to secondary metastasis and neuroendocrine disorders. Myeloproliferative leukemia is least common (2 cases, 3.3%), exclusively associated with juvenile disorders. These findings suggest reactive marrow changes dominate, driven by systemic conditions like hypersplenism, with other findings being less frequent. (Table 7)

Classification of Diagnoses into Hematological and Oncological Diseases:

Classification of Diagnoses into Hematological and Oncological Diseases shows the distribution of diagnoses among the 291 patients reveals that oncological diseases are significantly more common than hematological diseases, accounting for 64.6% (188 cases) of all findings. Among the oncological disorders, acute lymphocytic leukemia (ALL) was the most frequent single diagnosis with 34 cases (11.7%), followed closely by chronic myelogenous leukemia (CML) with 30 combined cases (10.3%) and multiple myeloma with 28 cases (9.6%). Other malignant or neoplastic conditions like chronic lymphocytic leukemia (CLL), myeloproliferative disorders (MPL, MPN), lymphomas, and metastatic tumors collectively contribute substantially to the overall cancer burden. In contrast, hematological (non-malignant) disorders made up 35.4% (103 cases) of the total. The most frequent within this group was megaloblastic anemia with 21 cases (7.2%), followed by reactive bone marrow changes in 28 cases (9.6%), indicating a considerable number of patients with reversible or non-neoplastic marrow responses. Aplastic anemia, ITP, Gaucher disease, and other marrow abnormalities such as fibrosis and osteosclerosis appeared in lower frequencies. (Table 8)

**Table 1.** AGE and Gender distribution.

AGE	Female (n,%)	Male (n,%)	Total (n,%)
Less than 1 year	2(0.69%)	2(0.69%)	4(1.37%)
1 to 12 years	19(6.53%)	24(8.25%)	43(14.78%)
13 to 18 years	11(3.78%)	12(4.12%)	23(7.90%)
19 to 40 years	28(9.62%)	29(9.97%)	57(19.59%)

AGE	Female (n,%)	Male (n,%)	Total (n,%)
41 to 60 years	48(16.49%)	39(13.40%)	87(29.90%)
61 to 75 years	25(8.59%)	41(14.09%)	66(22.68%)
more than 75 years	4(1.37%)	7(2.41%)	11(3.78%)
Total	137(47.08%)	154(52.92%)	291(100.00%)

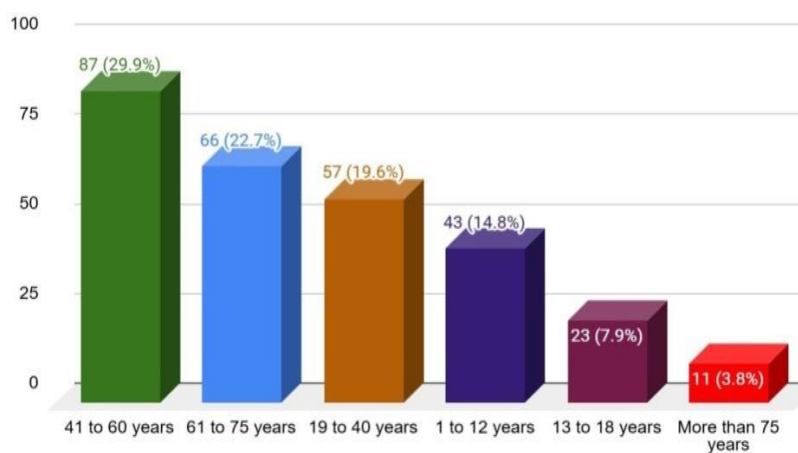


Figure 1. Age Group.

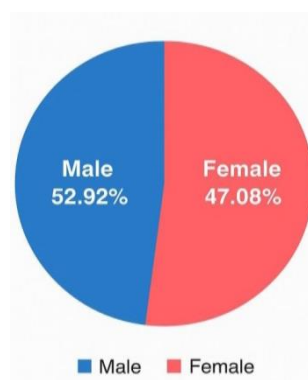


Figure 2. Gender distribution.

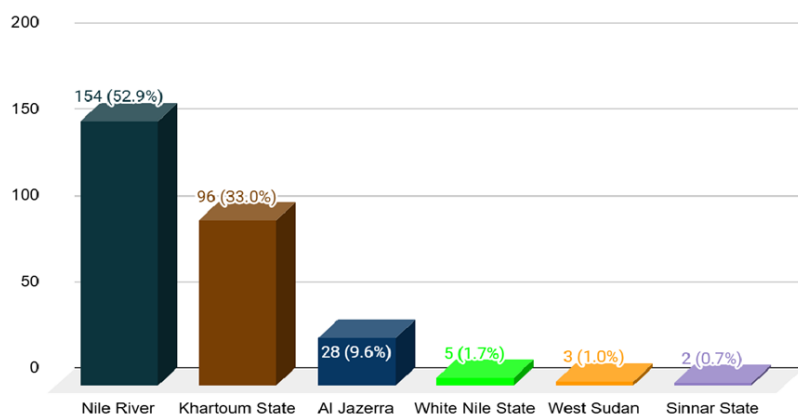
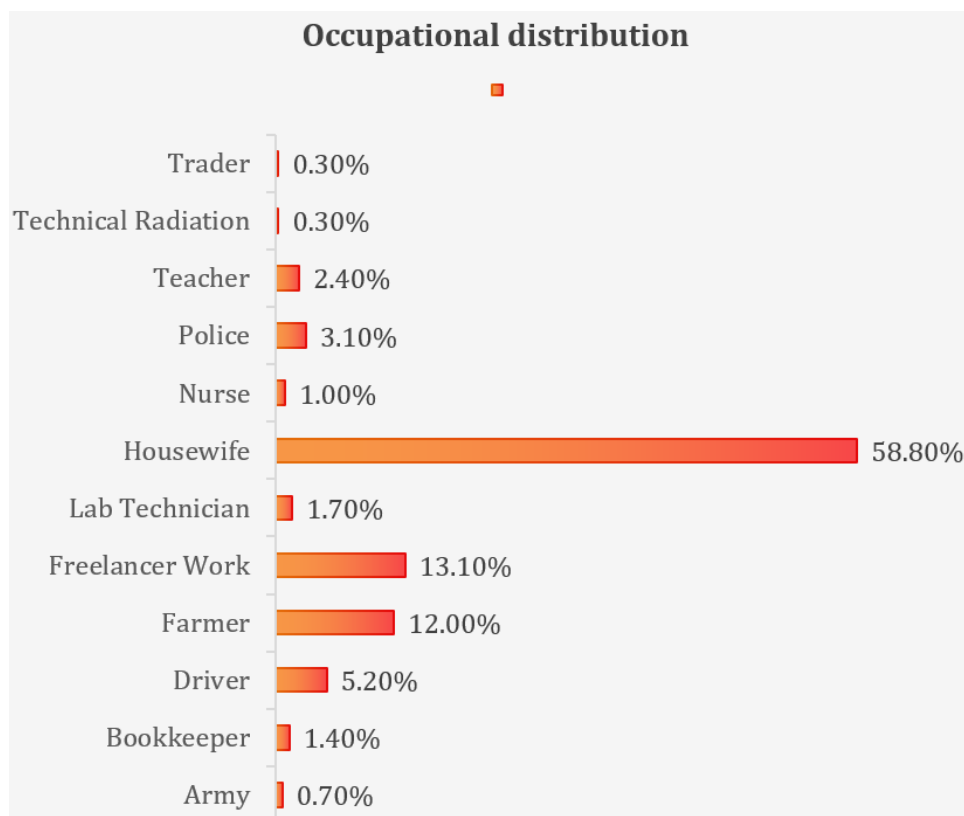


Figure 3. Residence distribution.

*Table 2. Occupation.*

Occupation	Frequency	Percent
Army	2	0.7%
Bookkeeper	4	1.4%
Driver	15	5.2%
Farmer	35	12.0%
Freelancer Work	38	13.1%
Lab Technician	5	1.7%
Housewife	171	58.8%
Nurse	3	1.0%
Police	9	3.1%
Teacher	7	2.4%
Technical Radiation	1	0.3%
Trader	1	0.3%
Total	291	100.0%

*Figure 4. Occupational distribution.*

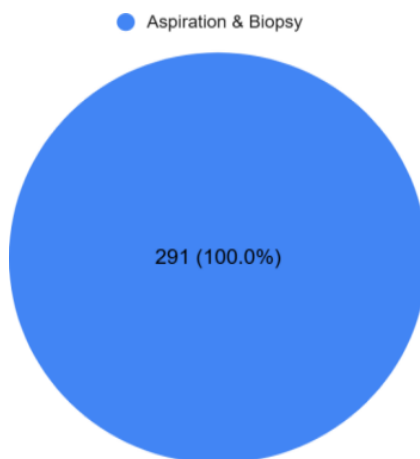


Figure 5. Types of investigations.

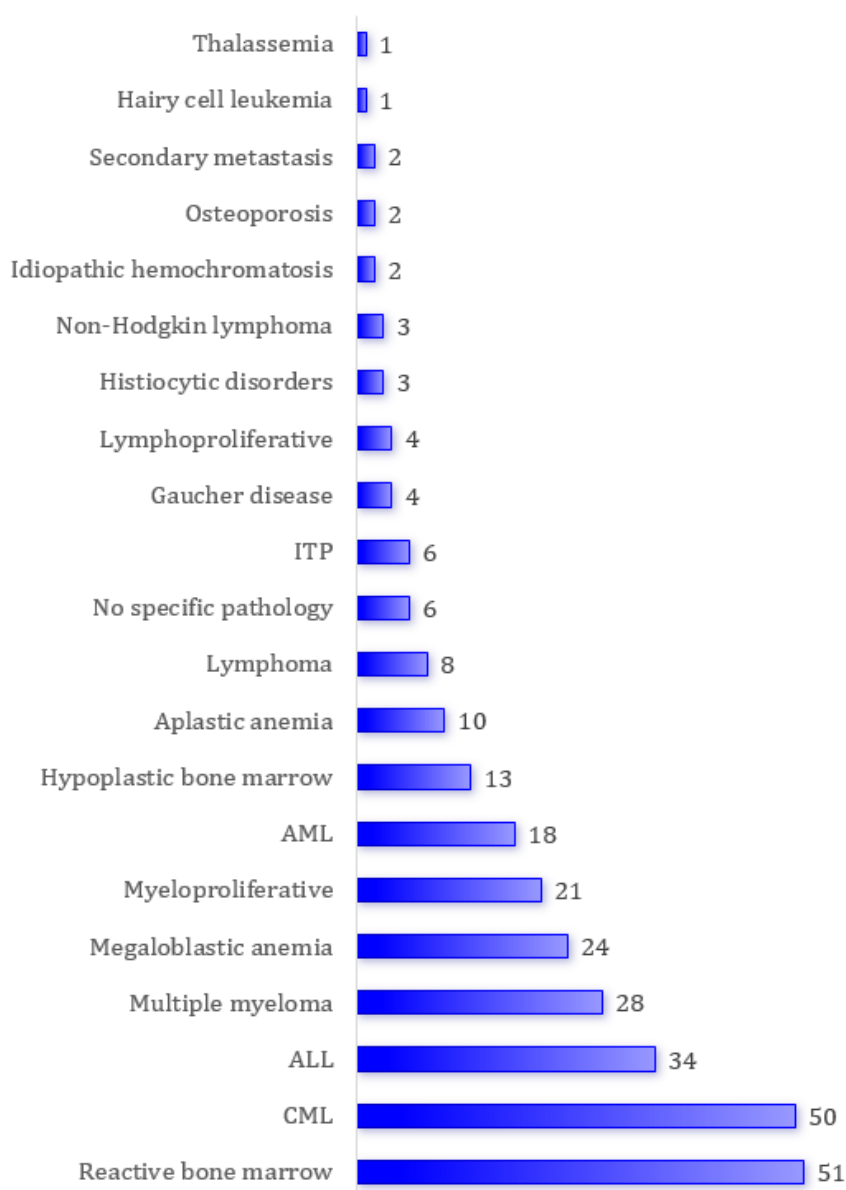


Figure 6. Diagnosis results distribution.

**Table 3.** Diagnosis results and AGE Cross tabulation.

Diagnosis Group	Pediatric (< 1 to 12 years)	Adolescent/Young Adult (13–40 years)	Middle Aged (41–60 years)	Elderly (61–75+ years)	Total
ALL, AML, CLL, HCL, Myeloproliferative	24	27	32	30	113
Aplastic, Megaloblastic, Thalassemia	5	7	10	13	35
Lymphoma, NHL, Lymph proliferative	0	7	6	2	15
Multiple Myeloma, Gaucher, Histiocytic	3	1	15	12	31
Hypoplastic BM, IHC, ITP, Osteoporosis, Secondary Metastasis	2	3	9	5	19
Reactive BM, No Specific Pathology	9	18	15	11	53
Total	43	80	87	77	291

**Table 4.** Diagnosis results and Residence Cross tabulation.

Diagnosis Group	Al Jazera	Khartoum State	Nile River	Other Regions	Total
ALL, AML, CLL, HCL, Myeloproliferative	15	42	63	3	113
Aplastic, Megaloblastic, Thalassemia	2	13	19	1	35
Lymphoma, NHL, Lymphoproliferative	3	6	5	1	15
Multiple Myeloma, Gaucher, Histiocytic	2	8	24	1	31
Hypoplastic BM, IHC, ITP, Osteoporosis, Secondary Metastasis	1	13	10	0	24
Reactive BM, No Specific Pathology	6	15	34	1	56
Total	28	96	154	13	291

**Table 5.** Distribution of Bone Marrow Diagnosis in Shendi and around Shendi.

Diagnosis Group	Almahmia	Begrawia	Grii	Hager Alasel	Kaboshia	Shendi	South Shendi	West Shendi	Total
Leukemias-ALL, AML, CLL, CML, MPL, MPN	0	0	4	10	3	26	0	8	51
Anemias Aplastic, Megaloblastic, Macrocytic	1	0	2	3	0	9	0	2	17
-Lymphoma, Related Disorders	0	0	1	0	0	2	0	1	4
Multiple Myeloma, Gaucher, Histiocytic	0	0	2	4	0	12	1	1	20
Hypoplastic BM, IHC, ITP, Fibrosis, Osteosclerosis, Secondary Mets	1	0	2	1	0	6	0	3	13
Reactive BM, No Specific Pathology	0	1	0	3	0	12	0	3	19
Total	2	1	11	21	3	67	1	18	124

**Table 6.** *Diagnosis results and Occupation Cross tabulation.*

Diagnosis Group	Professional	Skilled Labor	Unemployed	Total
Leukemias	7	29	77	113
ALL, AML, CLL, HCL, Myeloproliferative				
Aplastic, Megaloblastic, Thalassemia	3	9	22	35
Lymphoma, NHL, Lymphoproliferative	2	6	7	15
Multiple Myeloma, Gaucher, Histiocytic	4	14	14	31
Hypoplastic BM, IHC, ITP, Osteoporosis, Secondary Metastasis	3	7	11	21
Reactive BM, No Specific Pathology	2	19	36	57
Total	21	84	171	291

**Table 7.** *Bone Marrow Findings by Underlying Cause.*

Underlying Cause	Hypoplastic Bone Marrow	Myeloproliferative Leukemia	No Specific Pathology	Reactive Bone Marrow	Total
Hypersplenism	0	0	0	25	25
Peripheral Destruction (Immune-Mediated)	0	0	0	9	9
Peripheral Destruction (Other)	0	0	0	2	2
Exclude Multiple Myeloma	0	0	4	0	4
Secondary Metastasis	1	0	0	4	5
Infection (Tuberculosis/Malaria/Viral)	0	0	0	4	4
Lymphoproliferative Disorder (Staging)	0	0	0	1	1
Down Syndrome	0	0	0	1	1
Cytopenia (Immune, Lung Fibrosis)	0	0	1	0	1
Neuroendocrine Disorder	1	0	0	0	1
Juvenile Myeloproliferative Disorder	0	2	0	0	2
Thalassemia	0	0	0	1	1
Mixed Anemia	0	0	0	1	1
No Pathology	0	0	0	1	1
Total	3	2	5	51	61

**Table 8.** Classification of Diagnoses into Hematological and Oncological Diseases.

Diagnosis Group	Conditions Included	Frequency	Percent
Hematological Diseases	PRCA, Active bone marrow, Aplastic anemia, Megaloblastic anemia, Macrocytic anemia, Thalassemia, ITP, IHC, Gaucher disease, Bone marrow fibrosis/necrosis/osteosclerosis, Hypercellular BM, Hypocellular BM, Hypoplastic BM, Reactive BM, Osteoporosis, Renal osteodystrophy	103	35.4%
Oncological Diseases	ALL, AML, CML, CLL, HCL, Lymphoma, NHL, Multiple Myeloma, MPL, MPN, LPD, Secondary metastasis, Tumor, Histiocytic disorders	188	64.6%
Total		291	100.0%

## 8. Discussion

The present study provides critical insights into the spectrum of bone marrow examination findings among the Sudanese patient during a period of armed conflict, reflecting not only disease patterns but also the broader socio-economic and health disruptions that impact diagnostic outcomes.

The predominance of leukemia (38.8%) and non-specific reactive marrow changes (19.6%) is consistent with findings from previous studies in both Sudan and broader African contexts. For example, in North Sudan, Elmadhoun et al. identified aplastic anemia as the leading pathology in bone marrow aspirations conducted in Atbara, with a diagnostic yield of 76.8% [5].

In contrast, our data show a more prominent presence of leukemias and chronic lymphoproliferative conditions, possibly reflecting delays in healthcare access and diagnosis, leading to more advanced disease presentation.

Leukemia widespread presence across all age groups in our sample with peaks in middle-aged and elderly populations mirrors pan-African findings where both acute and chronic leukemia consistently feature as top malignant diagnoses [2, 6, 10].

This broad age distribution reinforces the role of bone marrow biopsy in diagnosing hematological malignancies across the life span.

Notably, the higher prevalence of chronic lymphocytic leukemia (CLL) and acute lymphoblastic leukemia (ALL) in our data aligns with trends reported in South Africa and Kenya [2, 10].

Furthermore, the concentration of leukemia cases in the River Nile and Khartoum States may reflect not only regional population densities but also varying degrees of health care infrastructure and accessibility.

The burden of non-malignant hematological disorders, including megaloblastic anemia and aplastic anemia, is also evident, albeit to a lesser extent. These findings are in line with studies from Nigeria and Ethiopia that emphasize nutritional deficiency anemias and bone marrow suppression due to infections, poor nutrition, or environmental exposures [6, 8].

Given the known impacts of conflict on food security, sanitation, and healthcare availability, our findings of 12% non-malignant anemia may underestimate the true prevalence, particularly considering the diagnostic limitations inherent to conflict settings.

The relatively high occurrence of reactive or non-specific bone marrow findings (19.6%) highlights another dimension of conflict-related health challenges. Such findings are often linked to infections, inflammatory processes, or general physiological stress all likely exacerbated by displacement, malnutrition, and psychosocial strain during conflict. Similar trends were observed in Malawi, where benign and reactive marrow changes constituted over 60% of findings, especially in immunocompromised populations [9].

The diagnostic profile of multiple myeloma, lymphomas, and histiocytic disorders in this study further demonstrates the importance of BME in identifying chronic and often late-stage malignancies. As in studies from India and South Africa, multiple myeloma showed a preference for older adults and was more frequently identified in urban centers with better healthcare access [10, 14].

The relative under representation of pediatric lymphomas, especially when compared to African pediatric studies where up to 27% of BME yielded malignancies [20], may reflect referral patterns, survival bias, or limitations in pediatric oncology services in Shendi.

Demographically, the preponderance of hematological abnormalities among unemployed individuals is noteworthy. While the study's chi-square test did not show a statistically significant association between occupation and diagnosis, the clear clustering of leukemia and anemia cases among those without formal employment suggests a potential social determinant of health. Similar findings have been reported in conflict zones, where economic instability correlates with higher disease burdens due to limited nutrition, healthcare access, and health literacy [7, 22].

The study's retrospective design, while necessary due to operational constraints during conflict, limits causal inference. Nonetheless, the statistically significant association between age and diagnosis ( $\chi^2 = 256.805$ ,  $p < .001$ ) reinforces known

age-related disease trends, while the weak association with occupation ( $p = .887$ ) may reflect limitations in occupational data classification

Importantly, the elevated proportion of expected counts below 5 in chi-square tests for occupation and residence (over 87% and 91%, respectively) suggests that larger, prospective studies with better stratification are needed to clarify these trends. The implications of these findings are profound.

The heavy burden of leukemia and reactive conditions amidst a backdrop of conflict underscores both a high diagnostic need and the fragility of health systems under duress. Studies from South Africa and Ethiopia highlight how limited diagnostics and delayed presentation compromise care, and these concerns are magnified in the context of active conflict [22].

Furthermore, operational challenges such as lack of pathologists, disrupted supply chains, and infrastructural damage—as outlined in the literature—likely affected both the performance and interpretation of BME in Shendi.

In conclusion, the data reveals a complex hematological landscape shaped by both biological disease processes and socio-political turmoil. The dominance of leukemias, the presence of significant non-malignant pathology, and the regional and occupational variations observed highlight the urgent need for improved diagnostic capacity, public health surveillance, and conflict-sensitive healthcare planning.

This study provides a critical evidence base for national health policy and offers a foundation for future research into the intersection between armed conflict and hematological disease burden in Sudan.

## 9. Conclusion

This study highlights a high burden of hematological malignancies and significant proportions of reactive and nutritional bone marrow disorders among Sudanese patients in a conflict-affected setting. The findings reflect delayed healthcare access, socioeconomic challenges, and limited diagnostic resources. Bone marrow examination remains an indispensable diagnostic tool in such environments. Addressing gaps in early detection, expanding diagnostic capacity, and implementing targeted public health interventions are essential to improving patient outcomes and reducing disease-related morbidity and mortality.

## 10. Recommendations

- 1) Strengthen early diagnostic services through mobile and outreach hematology units in underserved and conflict-affected areas.
- 2) Implement targeted screening programs for high-risk groups, particularly older adults and socioeconomically vulnerable populations.
- 3) Improve access to advanced diagnostic modalities such

as flow cytometry and molecular testing.

- 4) Enhance training of healthcare providers in early recognition and referral of hematological disorders.
- 5) Establish a national registry for hematological diseases to support surveillance and research.
- 6) Promote nutritional support programs, including micronutrient supplementation, to reduce preventable hematological conditions.
- 7) Improve medical record systems and data documentation for better research and clinical decision-making.

## 11. Limitations of the Study

- 1) Retrospective design limits the ability to establish causality.
- 2) Single-center study, which may limit generalizability to other regions of Sudan.
- 3) Possible selection biases, as only patients who reached the hospital and underwent BME were included.
- 4) Incomplete clinical data due to documentation challenges during conflict.
- 5) Lack of advanced diagnostic tools (e.g., flow cytometry, cytogenetics, and molecular studies) may have affected diagnostic accuracy and sub-classification.
- 6) Socioeconomic variables may not have been fully captured or standardized.

## Abbreviations

BME	Bone Marrow Examination
ALL	Acute Lymphocytic Leukemia
CLL	Chronic Lymphocytic Leukemia
AML	Acute Myelogenous Leukemia
CML	Chronic Myelogenous Leukemia
ITP	Idiopathic Thrombocytopenic
MPL	Myelo Proliferative Leukemia
IHC	Idiopathic Hemochromatosis
HCL	Hairy Cell Leukemia
NHL	Nonhodgkin Lymphoma
PRCA	Pure Red Cell Aplasia

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## Author Contributions

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**Baker Mohammed Saleh Hadi Gahaf:** Data curation, Investigation, Writing – original draft

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## Conflicts of Interest

The authors declared no conflict of interest.

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