Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 5, 2923-2939
2025
Publisher: Learning Gate
DOI: 10.55214/25768484.v9i5.7617

Spatiotemporal dynamics and humanitarian crisis in Bol (Chad): Satellite imagery analysis

Exaucé Gali Djako[1*], Gnimdou Aboukey[2], Komi Ameko Azianu[3], Komi Sélom Klassou[4], Jérôme Chenal[5,6]
[1]Regional Center of Excellence on Sustainable Cities in Africa (CERViDA-DOUNEDON/UL), University of Lomé, Lomé 01 BP 1515, Togo; galiexauce@gmail.com/exauce.galidjako@cervida-togo.org (E.G.D.).
[2]Applied Remote Sensing and Geoinformatics Laboratory (LTAG), University of Lomé, Lomé 01 BP 1515, Togo.
[3]Higher Institute of Population Sciences, Joseph Ki-Zerbo University, 03 BP 7021, Ouagadougou, Burkina Faso.
[4]Research Laboratory on the Dynamics of Environments and Societies (LARDYMES), University of Lomé, Lomé 01 BP 1515, Togo.
[5]School of Architecture, Civil and Environmental Engineering, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland.
[6]Mohammed VI Polytechnic University (UM6P) Center of Urban Systems (CUS), Ben Guerir 43150, Morocco.

Abstract: This study investigates the impact of protracted humanitarian crises on urban development in Bol, a city in Chad's Lake region, with a focus on spatial transformations and planning implications. The purpose is to assess how displacement-driven urbanization has altered land use patterns and to inform more adaptive urban planning in fragile contexts. A mixed-methods approach was adopted, combining satellite imagery (Landsat, 1992–2023), demographic data, field surveys, and displacement records. Land use and land cover changes were mapped using a supervised classification technique based on the Support Vector Machine (SVM) algorithm. The results show a significant urban expansion of 60.57% between 1992 and 2016, followed by a slower growth rate of 3.86% from 2016 to 2023, primarily at the expense of agricultural land (−25.64%), sandy soils (−59.52%), and wetlands (−94.33%). The planned resettlement of 6,860 internally displaced persons (IDPs) in 2024 is expected to require an additional 73.1 hectares, putting further pressure on local land and infrastructure. The study concludes that remote sensing offers a critical tool for monitoring urban change in crisis-affected regions and underscores the need for spatially informed, sustainable urban planning strategies in rapidly transforming and ecologically vulnerable urban areas.
Keywords: *City of Bol, Humanitarian crises, Lake Chad, Satellite imagery, Spatiotemporal dynamics.*

1. Introduction

Humanitarian crises are increasingly reshaping urban landscapes, driven by the convergence of socio-political instability and environmental stressors [1, 2]. In the Global South, particularly in fragile states, the resulting forced migrations are placing significant pressure on urban systems that are often under-resourced and unprepared for sudden demographic shifts. Chad exemplifies this situation, with more than a third of its population requiring humanitarian assistance as of 2024. Ongoing armed conflicts, climate-induced hazards, food insecurity, and public health emergencies have been compounded by the mass influx of refugees from Sudan, over one million in 2023, with an additional 250,000 expected in 2024 [3]. These movements intensify the strain on infrastructure and natural resources, particularly in secondary urban centers such as Bol, located in the Lac Province.

Bol has seen substantial population growth, fueled by insecurity, flooding, and the seasonal return to fishing and farming zones. According to IOM data, the city hosted nearly 40,000 displaced persons as of early 2024 [4]. This influx is accelerating the development of informal settlements and

History: Received: 18 March 2025; Revised: 5 May 2025; Accepted: 9 May 2025; Published: 28 May 2025
* Correspondence: galiexauce@gmail.com

overburdening already limited infrastructure. The spatial expansion of Bol is now extending into adjacent rural villages, including Tchaïrom, Moun, and Birim, disrupting traditional land uses and increasing environmental pressure.

Chad's urbanization, though relatively modest in scale (24% in 2023), is progressing at an annual rate of 4.5% [5]. Yet urban development remains largely spontaneous and unregulated due to the absence of enforceable urban planning frameworks, as seen in the capital, N'Djamena [6]. Conventional land development practices—characterized by large plot sizes and formal market constraints- further marginalize vulnerable groups, pushing displaced populations toward informal settlements [7]. These dynamics complicate land management and hinder efforts to build resilient urban systems.

In Bol, where the built environment coexists with polders, wetlands, and lake inlets, spatial planning is further constrained by complex topographic conditions [8]. Current population densities vary widely—from under 70 inhabitants per hectare in surrounding villages to over 200 in central districts—posing additional challenges for service delivery and land-use regulation. These spatial patterns reflect not only demographic pressures but also deep-seated territorial imbalances exacerbated by recurrent crises [9].

In this context, satellite imagery offers a powerful tool for assessing and guiding urban development in crisis-affected environments. Its multispectral, multi-temporal capabilities allow researchers and planners to track land-use change, quantify urban growth, and detect areas under pressure from migration and environmental degradation [10, 11]. Remote sensing models, such as U-Net, have shown strong performance in distinguishing built-up areas from agricultural or ecologically sensitive zones [12, 13]. In fragile settings like Bol, such technologies can support both emergency response and long-term urban planning.

This study addresses this gap by examining how successive humanitarian crises have influenced the spatial development of Bol over the past three decades. Using satellite imagery (Landsat time series), supervised classification with the Support Vector Machine (SVM) algorithm, and demographic and displacement data, the research analyzes land use changes between 1992 and 2023. It aims to: (1) identify the dominant land-use categories; (2) examine their spatiotemporal evolution; and (3) estimate the spatial demands resulting from forced displacement. Unlike previous studies that focus primarily on large cities or refugee camps, this research centers on a mid-sized, under-documented urban area at the intersection of multiple crisis vectors. Its originality lies in the integration of geospatial analysis with humanitarian data to inform urban planning in a context of chronic instability. The research question guiding this study is: How have humanitarian crises influenced land use dynamics and urban expansion in Bol, and what are the spatial implications for planning and resource allocation?

2. Literature Review

2.1. Humanitarian Crises and Urban Development

The increase in forced displacement has become a worrying global phenomenon. By the end of 2022, there will be 108 million forcibly displaced people in the world, including 35.3 million refugees [14]. In addition, there are people displaced because of recent crises in several countries in the region. This situation is more worrying in Africa, where it is estimated that by 2023, there will be 40.4 million forcibly displaced Africans, more than double the figure for 2016 [15]. Over the past two decades, the border towns of the Lake Chad Basin (LCB) region have become the scene of a humanitarian crisis due to a cycle of conflict and fragility [16, 17].

In this context of growing forced displacement, a major shift is observed in the choice of refuge locations, with increasing numbers of displaced people opting for cities rather than conventional camps [18]. The proportion of people displaced to urban areas is steadily increasing, as evidenced by the fact that in 2016, 60% of refugees lived in these areas [19]. Not only is the number of people displaced to cities increasing, but the length of their journeys is also lengthening. Indeed, the average duration of refugee displacement is estimated at 26 years, highlighting the scale of the long-term needs that humanitarian initiatives must address [20]. This dynamic has led millions of people to live in prolonged transit, illustrating the scale of the protraction phenomenon [21]. The evolution of refugee camps towards urban and peri-urban type spaces, mainly due to prolonged displacement situations, is observed in several contexts in Africa [22]. In the context of this transition, the identification of displaced persons residing in urban areas remains a challenge because displaced populations are often integrated into urban environments that cannot be formally identified [23]. Moreover, in the case of displacement to border towns, ethnic links between displaced people and host populations often exist, providing refugees with an extensive and protective network that can accelerate their integration [24]. This transition from camps to integration in host cities is supported by policies such as 'alternatives to camps,' which encourage the integration of refugees into urban communities [25]. This development of humanitarian crises in urban areas generates specific challenges in terms of managing displaced populations and coordinating humanitarian efforts [26].

Faced with this reality, global agendas have begun to recognize the crucial importance of humanitarian crises in urban environments. In 2016, the establishment of the Global Alliance for Urban Crises at the first World Humanitarian Summit was evidence of this collective awareness, as it aimed to improve preparedness and response to crises in urban environments through interdisciplinary collaboration [27]. In addition, the new urban agenda issues from Habitat III highlight the need to protect the rights of displaced populations and provide support to local governments to facilitate their integration into existing urban structures [28].

Responses to humanitarian crises in urban areas have become vitally important, with the need to target both displaced and host populations. This imperative considers the fact that these populations are often intermingled and have very similar immediate needs [29]. From this perspective, local governments play a crucial role in addressing urban humanitarian crises. However, this necessitates a deeper understanding of existing urban systems and their interconnections by humanitarian actors.

Current research on humanitarian crises and urban development emphasizes key dynamics such as increased forced displacement to urban areas, challenges in integrating refugees, and necessary humanitarian responses to address these complex needs. Nonetheless, several gaps persist. Firstly, existing studies often lack comprehensive exploration of the specific characteristics of border towns, especially regarding ecological vulnerability and limited institutional capacity to manage influxes of displaced populations. Secondly, the shift from camps to urban areas is frequently addressed generically, without detailed analysis of the long-term socio-economic and spatial impacts on urban infrastructure. Lastly, the interactions between host populations and displaced persons are insufficiently studied, particularly in contexts where ethnic ties may exist, but tensions can still arise. These deficiencies underscore the need for a more systematic and context-sensitive approach, incorporating longitudinal data and better integrating ecological and social dimensions into urban settlement strategies.

2.2. Using of GIS in Spatial Dynamics in Connection with Humanitarian Crises

Research in urban planning has extensively leveraged advances in satellite imagery to analyze intra-urban development patterns. In particular, the use of Very High Resolution (VHR) satellite imagery has proven highly effective in numerous recent studies, allowing researchers to collect detailed quantitative and spatial data [30, 31].

At the same time, technological advances in geographic information systems (GIS) have also played a crucial role in the analysis of urban patterns. The integration of high spatial accuracy satellite data with GIS has made it possible to obtain accurate quantitative measures of urban growth, thus providing a rational and justifiable basis for studies on rapid urbanization [32, 33].

Population pressure can lead to changes in land use and land cover; these can be monitored using geographic information systems (GIS), and their impact analyzed using remote sensing methods [34].

Research has shown that satellite imagery, even of coarser resolution such as Landsat, can be effectively used to monitor land use change, deforestation, reforestation, and settlement expansion, especially during and after conflicts [35, 36]. The rapid development of GIS provides abundant imagery resources that can be used to build long-term time series and spatial distribution maps of urban land with high accuracy [37]. This ability to track changes in urban areas offers valuable insights into understanding urban evolution, post-conflict reconstruction, and urban planning.

Furthermore, the use of satellite imagery for monitoring urban areas has garnered increasing interest in the field of humanitarian aid. Indeed, time series of satellite images, such as those obtained from Landsat and Sentinel satellites, have been employed to analyze the evolution of refugee settlements and crisis-affected areas [38, 39]. This application of geospatial approaches in the humanitarian sector has advanced rapidly in recent years, providing new tools to assess the needs of populations affected by crises [40].

Finally, it is essential to highlight the role of Geographic Information Systems (GIS) as a decision-support tool in conflicts and negotiation processes. GIS provides a platform for integrating and analyzing spatial data to facilitate a better understanding of territorial and environmental challenges in conflict zones [41]. This ability to deliver objective data can contribute to fostering informed dialogue and supporting sustainable peace processes.

However, using satellite data in crises comes with important limitations. Data availability and quality can be compromised by factors like cloud cover, low temporal resolution, or restricted access in conflict zones. Additionally, many studies remain heavily technical, often failing to connect geospatial insights with the local social and political realities. Elements such as land ownership systems, power imbalances, or how communities perceive displacement are rarely included in spatial analyses, even though they are crucial for effective urban planning and humanitarian action. Ethical concerns are also frequently overlooked. Mapping vulnerable populations can raise serious risks around privacy, surveillance, and potential misuse of data. In fragile settings, publishing geospatial data, such as the locations of settlements or migration routes, can unintentionally put people at risk of harm or exploitation. There is increasing recognition of the need to use spatial technologies responsibly, with measures like data anonymization, informed consent, and alignment with local governance frameworks.

Ultimately, while GIS and remote sensing are powerful tools for analyzing crisis-affected areas, their use must extend beyond technical performance to consider the broader human context. A more critical, interdisciplinary approach is needed—one that combines geospatial accuracy with contextual sensitivity, integrates ethical safeguards, and supports inclusive decision-making in the face of humanitarian pressures.

3. Materials and Methods

3.1. Study Area

Located in the Lac Province of Chad, Bol is the provincial capital. It is situated on the shores of Lake Chad, on a continental arm between the 14th degree of northern latitude and the 12th degree of eastern longitude. The city lies approximately 350 km northwest of N'Djamena. Due to its strategic geographical position, Bol benefits from its proximity to the borders of Nigeria, Niger, and Cameroon.

Administratively, Bol was designated as a municipality by Decree No. 564/PR/87 of 28 October 1996. The city is situated within a highly active commercial exchange network and is distinguished by an economy predominantly based on primary sector activities [42]. Its economic significance is further reinforced by substantial agricultural production from the polders of Lake Chad. Figure 1 below is a map showing the location of the town of Bol.

DOI: 10.55214/25768484.v9i5.7617

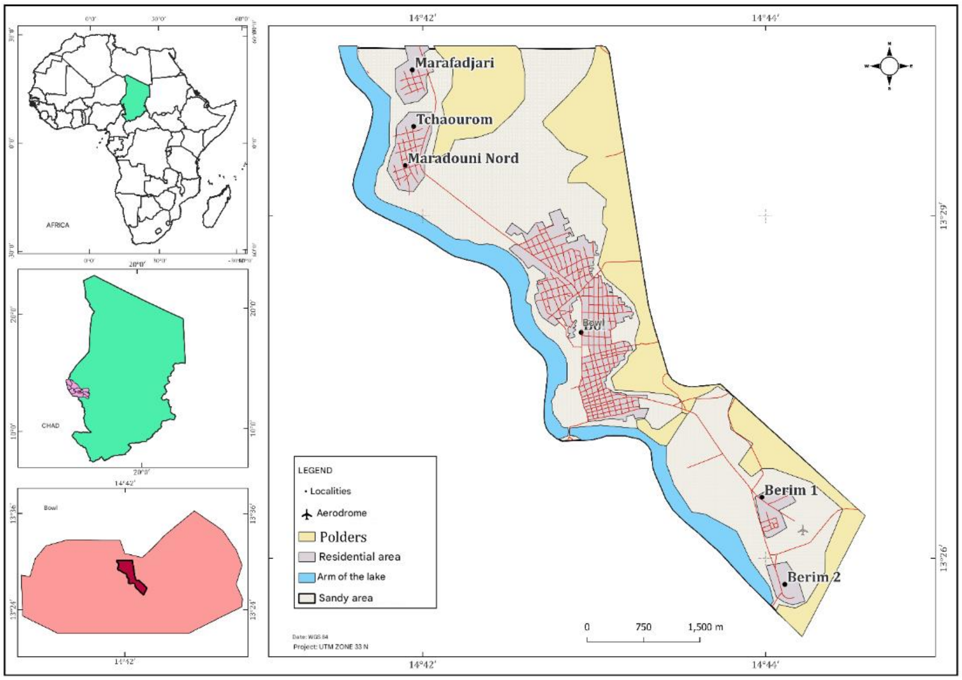

Figure 1.
Geographical location of the city of Bol.

3.2. Data

This study relies on various types of data to analyze the spatiotemporal dynamics of the city of Bol about humanitarian crises.

3.2.1. Satellite Imagery Data

Satellite images were used to map land use changes for the reference years 1992, 2016, and 2023. The year 1992 was chosen due to its proximity to the first General Population and Housing Census (RGPH 1), conducted in 1993, which provides a historical basis for comparison. In 2016, large-scale migration flows began into Lac Province, driven by the humanitarian and security crises unfolding in the region. Finally, 2023 corresponds to the period of field data collection.

The satellite images were sourced from the Landsat 5, 7, and 8 sensors via the USGS Earth Explorer platform (https://earthexplorer.usgs.gov/) [43]. These images, with a spatial resolution of 30 meters, are well-suited for regional-scale territorial transformation analysis. Landsat imagery was selected as it meets the specific requirements of this research, unlike other available satellite data. Firstly, Landsat provides continuous coverage over the study period from 1992 to 2023, whereas other satellites such as Sentinel-2 or SPOT lack archival data extending as far back. Secondly, while high-resolution imagery from satellites like WorldView or Pleiades offers greater detail, their temporal coverage is limited, and acquisition costs are significantly higher. In contrast, Landsat provides a sufficient spatial resolution for analysing territorial dynamics while remaining freely accessible via NASA and USGS platforms. Table 1 below presents the characteristics of the Landsat images used.

ISSN: 2576-8484
Vol. 9, No. 5: 2923-2939, 2025
DOI: 10.55214/25768484.v9i5.7617

Table 1.
Characteristics of the Landsat images used.

Year	Landsat	Scenes (Path/Row)	Sensors	Spatial Resolution	Acquisition Date	Cloud Cover (%)
1992	5	PATH = 185, ROW = 051	TM	30 m	1992-12-22	0.00
2016	7	PATH = 185, ROW = 051	OLI_TIRS	30 m	2016-12-16	0.01
2023	8	PATH = 184, ROW = 051	OLI_TIRS	30 m	2023-12-29	0.00

3.2.2. Demographic Data

Demographic information was used to analyze population trends and their impact on land use. These data were mainly sourced from the General Population and Housing Censuses, along with demographic projections published by the National Institute of Statistics, Economic Studies, and Demography (INSEED). They enable the establishment of a correlation between demographic trends and urban expansion as observed in satellite imagery.

3.2.3. Data on Humanitarian Crises and Migration

Data on humanitarian crises and migration flows were extracted from reports by the International Organization for Migration (IOM) and the Office for the Coordination of Humanitarian Affairs (OCHA), as well as from government documents and publications by specialized research institutions. These data provide essential contextual elements for understanding the impact of crises on the urban and territorial dynamics of Bol.

The assessment of the needs of internally displaced persons (IDPs) settling in Bol follows a methodological approach that combines demographic analysis with the application of urban planning standards in Chad. The process begins with estimating the number of displaced persons settling in the city, followed by calculating the number of households based on the average household size. From this figure, the required surface area is determined by applying Chad's residential plot allocation standards. To ensure structured urban planning, an additional area is incorporated to accommodate infrastructure, including road networks and public utilities. This approach enables a comprehensive estimation of the space required, thereby facilitating the spatial organization, and planning of settlements.

3.2.4. Field Data

Satellite and demographic data were supplemented with direct field observations. These observations refined the analysis of spatial transformations and helped identify recent dynamics that were not discernible from secondary data alone.

3.3. Methods

3.3.1. Determination of Land Use and Land Cover (LULC) Classes

In the initial phase, five land use and land cover (LULC) classes were defined: urban settlements, polders and agricultural zones, water bodies, sandy soils (dunes), and wetlands [44]. Table 2 presents Main Land Use and Land Cover Classes in Bol

Table 2.
Mainland Use and Land Cover Classes in Bol.

Land Use Unit	Characteristics
Urban Agglomeration	Built-up and densely populated areas represent urban expansion driven by demographic growth and pressure on infrastructure.
Polders and Cultivated Areas	Agricultural lands, often located in flood-prone zones, are primarily dedicated to maize cultivation and other subsistence crops.
Water Bodies	Aquatic areas, including Lake Chad, supporting economic activities such as fishing and irrigation, are subject to seasonal variations.
Sandy Soil	Areas resembling dunes.
Wetlands	Permanently or seasonally wet areas formed during the rainy season, are crucial for water regulation and marginal economic activities.

3.3.2. Satellite Data Processing

The processing of satellite data commenced with a crucial preprocessing stage. Initially, radiometric correction was applied to enhance the accuracy of reflectance data. The Dark Object Subtraction (DOS) method, implemented using QGIS software, was employed to eliminate atmospheric interferences by subtracting dark pixels, thereby significantly improving image quality [45, 46]. Subsequently, a multispectral combination was performed using the "layer stacking" tool to merge different spectral bands, ranging from visible to infrared, into a single composite image. This step was essential for generating a comprehensive image capable of capturing subtle territorial details across multiple wavelengths [47].

Following preprocessing, the study area was extracted from the images using a shapefile layer corresponding to the city of Bol. The "Extraction" tool in QGIS was utilized to crop the images based on this geographic boundary, thereby focusing the analysis exclusively on the urban perimeter. Subsequently, image color composition was conducted to facilitate the visualization of territorial transformations. Two types of compositions were employed: true color, which replicates human visual perception, and false-color infrared, which enhances vegetation and wetland areas. These compositions were instrumental in understanding territorial dynamics by highlighting variations in vegetation cover and land use [48, 49].

3.3.3. Classification of Multispectral Images

The next stage involved the classification of multispectral images. This analysis was conducted using a supervised classification method, which required the creation of training areas or Regions of Interest (ROI). Once the ROI was established, the Support Vector Machine (SVM) algorithm was applied to classify each pixel according to its spectral signature. The algorithm aimed to optimize the separation of different classes by maximizing the margin between them, allowing for the precise assignment of each pixel to a specific category. This process facilitated an accurate assessment of land-use changes over time [50, 51]. Studies have shown that SVM often outperforms RF and other traditional classifiers (e.g., Maximum Likelihood, k-NN) in heterogeneous urban landscapes, particularly when class boundaries are complex, and the sample size is limited. Moreover, SVM's capacity to model class boundaries using kernel functions makes it well suited for distinguishing between land cover types with subtle spectral differences, a key requirement for detecting transitional zones affected by human settlement and ecological degradation.

3.3.4. Post-Processing of Results

Finally, post-processing was conducted to refine the classification. This stage involved the application of spatial filters to correct errors and eliminate misclassified areas. The classified data were then vectorized to enable in-depth spatial analysis and the creation of precise thematic maps. This process translated spatio-temporal changes into actionable geographic information, which was critical for interpreting urban dynamics in Bol about humanitarian crises [52].

These successive steps led to the identification of the mainland-use types in Bol over the past decades and facilitated the examination of spatio-temporal trends in these transformations.

3.3.5. Validation of Classification Results Using the Kappa Index

The Kappa index, introduced by Cohen [53] is a statistical measure that assesses the agreement between two classifications while accounting for the expected agreement by chance [54]. It is widely used in satellite image analysis to evaluate the accuracy of thematic classifications by comparing a classified map with reference data (ground truth). This index generally ranges from -1 to 1, where a value close to 1 indicates excellent agreement, while a value near 0 suggests an agreement equivalent to chance. Its calculation formula is given by:

$$k = \frac{Po - Pe}{1 - Pe}$$

ISSN: 2576-8484
Vol. 9, No. 5: 2923-2939, 2025
DOI: 10.55214/25768484.v9i5.7617

With Po (observed agreement) is the proportion of correct classifications (sum of true positives).

Pe (random agreement) is the proportion of agreement expected by chance.

Validation of the classification result with field data

The classification process was validated by comparing the results obtained with field data to assess the model's accuracy. For each land use class, 20 field points were used to verify the classification accuracy. The results of this validation are as follows:

Water bodies: 20/20 (100%) - Classification fully consistent with field observations.

Conurbations: 20/20 (100%) - All control points were correctly classified.

Polders and cultivated areas: 16/20 (80%) - Four misclassifications likely due to confusion with bare soil areas or marshes.

Swamps: 14/20 (70%) - Six misclassifications, possibly related to spectral similarity with cultivated areas or shallow water.

Sandy soils: 18/20 (90%) - Two minor misclassifications may be due to variations in soil moisture.

3.3.6. Identifying Needs Arising from Humanitarian Crises

The identification of spatial needs resulting from humanitarian crises in Bol is based on an analytical approach combining demographic data and urban planning standards applicable in Chad. The assessment considers the displaced population settled in the city, enabling the determination of household numbers based on the average household size. From this estimation, the required land area for household settlement is calculated by applying the standard plot occupancy rate. Additionally, to ensure structured and functional urban planning, a land reserve is integrated for road networks and essential infrastructure, guaranteeing a spatial organization that is coherent and adapted to the needs of displaced populations. Figure 2 presents the global methodological approach.

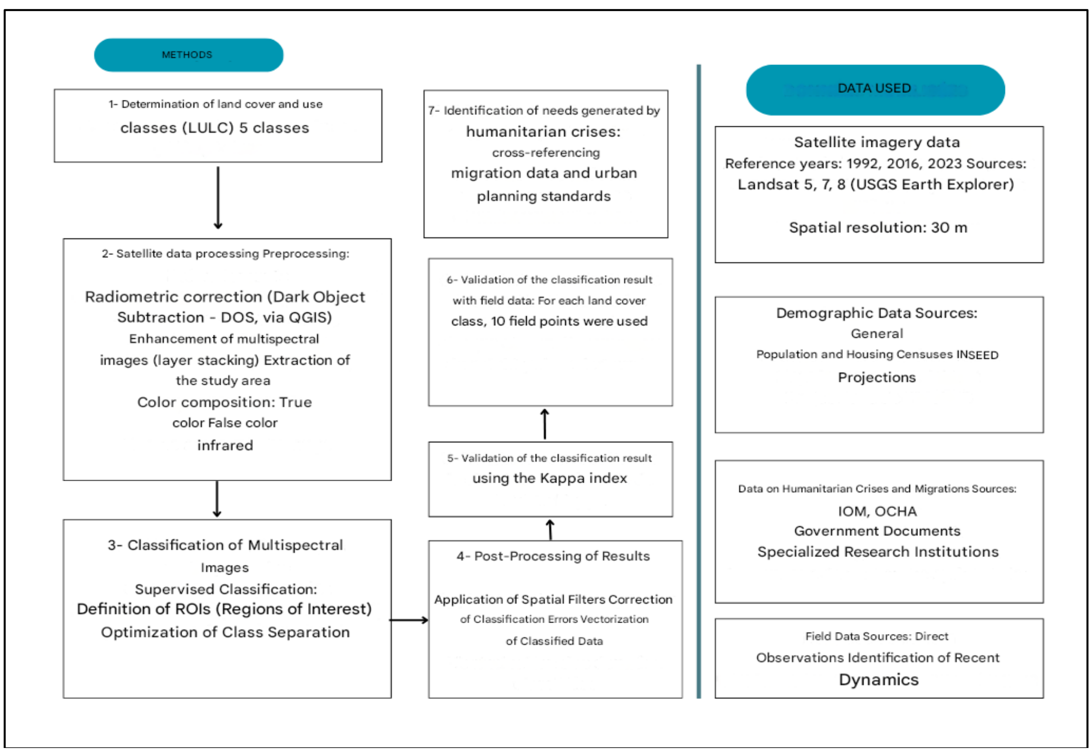

Figure 2.
Global methodological approach.

4. Results

4.1. Dynamics of Land use and Land Cover in the City During the Study Period

The supervised classification conducted using the Support Vector Machine (SVM) algorithm identified five land use units in Bol, each characterized by specific attributes. The accuracy at the pixel level is presented in Table 3 below.

Table 3.
Overall classification accuracy using the Support Vector Machine (SVM) algorithm.

Year	Kappa Index	Overall Accuracy (%)
1992	84	88
2016	81	85
2023	90	92

Analysis of the Spatio-Temporal dynamics of major land use types.

Table 4.
Dynamic of major land use types.

Land Use Unit	1992 - Area (ha)	1992 - %	2016 - Area (ha)	2016 - %	2023 - Area (ha)	2023 - %
Urban Agglomeration	665.73	34.84	1,068.93	55.95	1,110.15	58.10
Polders and Cultivated Areas	619.56	32.43	460.71	24.11	429.48	22.48
Water Bodies	197.82	10.35	215.64	11.29	207.36	10.85
Sandy Soils	405.27	21.21	164.07	8.59	163.62	8.56
Wetlands	22.23	1.16	1.26	0.07	0	0
Total	1,910.61	100	1,910.61	100	1,910.61	100

The evolution of land cover between 1992, 2016, and 2023 highlights contrasting dynamics in land use.

The urban agglomeration has expanded considerably over the past decades, growing from 665.73 hectares in 1992 to 1,068.93 hectares in 2016, and reaching 1,110.15 hectares by 2023. This steady growth highlights a rapid urbanization process, often occurring at the expense of other land uses, particularly farmland and natural spaces. Polders and cultivated areas have notably decreased, from 619.56 hectares in 1992 to 460.71 hectares in 2016, and down to 429.48 hectares in 2023. This decline points to mounting urban pressure and the gradual conversion of agricultural land into urban areas.

Water bodies saw a modest increase of 17.82 hectares between 1992 and 2016, followed by a slight reduction of 8.28 hectares from 2016 to 2023. These fluctuations could stem from hydrological changes, human activities, or climate-related variations impacting water systems. Sandy soils underwent a substantial loss of 241.2 hectares between 1992 and 2016, then stabilized between 2016 and 2023 with only a slight reduction of 0.45 hectares. This shift likely reflects the encroachment of urban development into natural areas.

Wetlands have almost completely vanished, shrinking from 22.23 hectares in 1992 to just 1.26 hectares in 2016, and disappearing entirely by 2023. This dramatic transformation signals the loss of wetland ecosystems, primarily driven by human actions such as land reclamation and drainage for agriculture or urban expansion.

The evolution of the various land use units between 1992 and 2023 is illustrated in Figure 3 below.

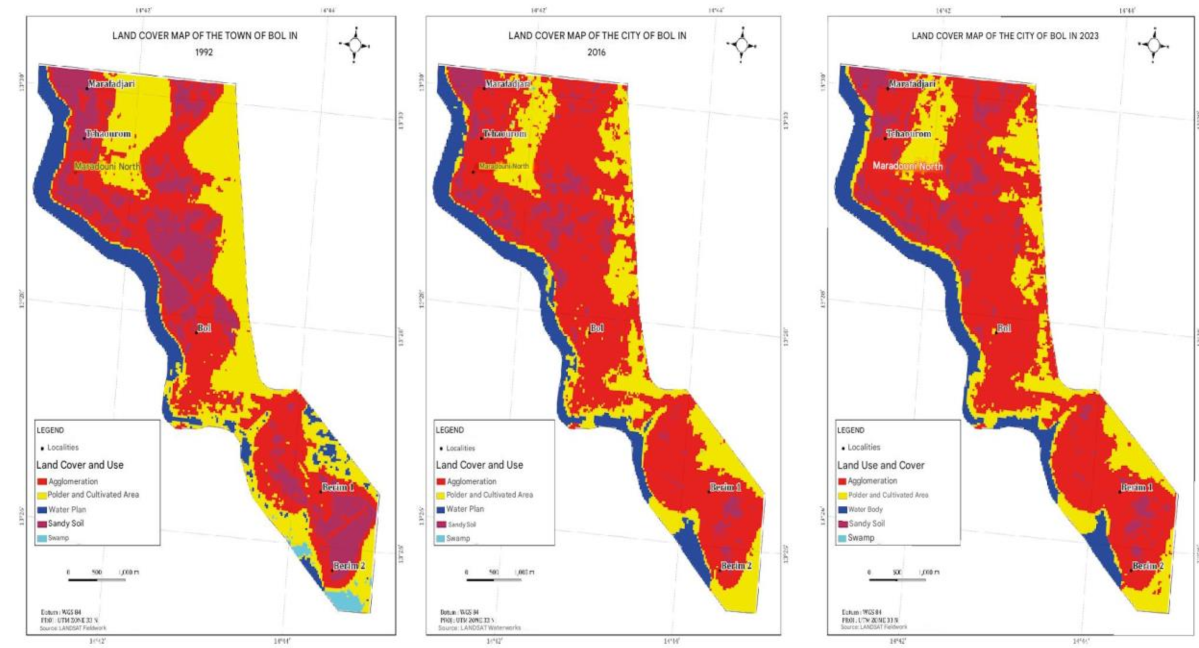

Figure 3.
Evolution of the various land use units between 1992 and 2023.

Figure 3 illustrates the evolution of different land use units, highlighting a clear trend of urban expansion.

Table 5.
Trends in land use change over the study periods.

Land Use Units	Change 1992-2016 (ha)	Balance 1992-2016	Change 2016-2023 (ha)	Balance 2016-2023
Urban Agglomeration	+403.2	Gain	+41.22	Gain
Polders and Cropland	-158.85	Loss	-31.23	Loss
Water Bodies	+17.82	Gain	-8.28	Loss
Sandy Soils	-241.2	Loss	-0.45	Loss
Wetlands	-20.97	Loss	-1.26	Loss
Total	0	-	0	-

4.2. Analysis of Land use Change Trends

An analysis of the land use balances between 1992–2016 and 2016–2023 reveals major trends.

Urbanization emerges as the dominant trend, with an increase of 403.2 ha between 1992 and 2016, followed by a further gain of 41.22 ha between 2016 and 2023. Although the pace of expansion has recently slowed, urban sprawl continues to reshape the territory's spatial structure. Agricultural land has been particularly affected, shrinking by 158.85 hectares between 1992 and 2016, and losing another 31.23 hectares between 2016 and 2023. This ongoing reduction raises concerns about the future of local food security. Water bodies have shown irregular patterns, with a modest increase of 17.82 hectares at first, followed by a decrease of 8.28 hectares, reflecting instability in water resource management. These changes may be driven by both climate variability and human activity. The near-complete loss of wetlands, 22.23 hectares over three decades, is particularly troubling, as it threatens biodiversity and disrupts hydrological balance.

Lastly, sandy soils have declined sharply, with 241.2 hectares lost between 1992 and 2016. Since then, the situation has remained relatively stable, but the long-term implications remain concerning.

This suggests a landscape transformation potentially driven by urbanization and the conversion of natural areas. The trends in land use change are illustrated in Figure 4 below.

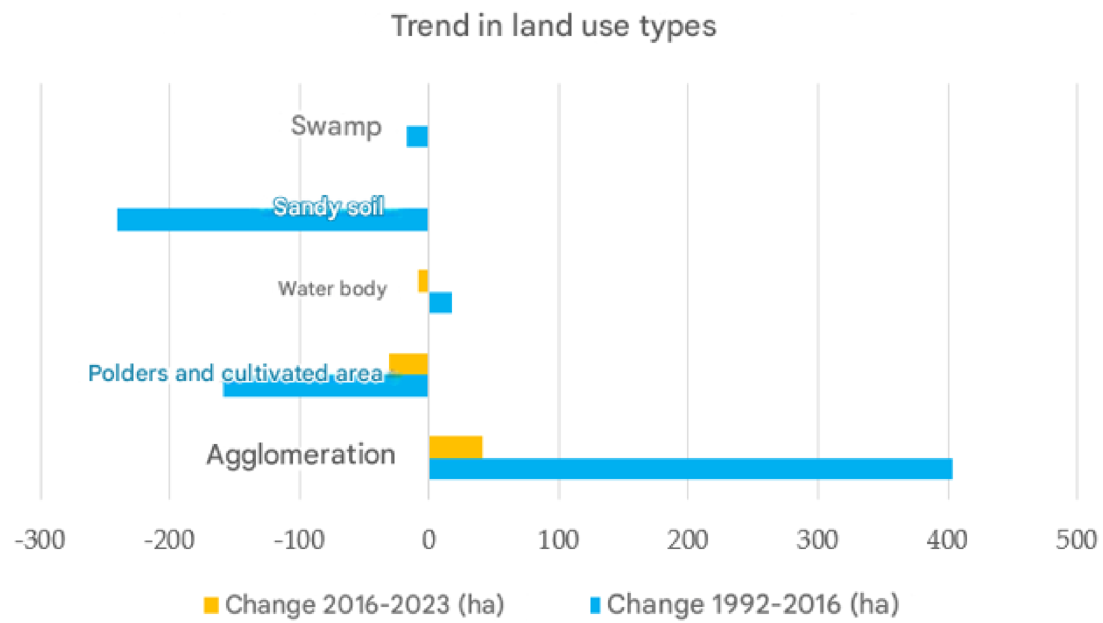

Figure 4.
Illustration of trends in land use change.

4.3. Humanitarian Crises and Urban Growth in Bol

The city of Bol, located in the Lac Province of Chad, is experiencing a complex dynamic driven by successive humanitarian crises that have led to significant population displacements. These migratory movements directly influence demographic growth in the region, with profound implications for resource management and spatial planning.

4.3.1. Displacement Trends in Bol

Table 6 below presents the number of displaced persons in the sub-prefecture of Bol.

Table 6.
Number of displaced persons in the sub-prefecture of Bol in 2024.

Year	IDPs	Returnees from Abroad	Former IDPs	Total Displaced Population
2019	18,714	2,559	10,726	31,999
2020	51,509	1,766	6,458	59,733
2021	61,002	1,886	5,283	68,171
2022	26,500	1,386	6,068	33,954
2023	30,311	2,062	7,113	39,486
2024	36,035	1,985	7,709	45,729

Data collected from 2019 to 2024 reveal a notable fluctuation in the number of Internally Displaced Persons (IDPs) and returnees (both from abroad and former IDPs). IDPs constitute most of the displaced population, peaking in 2021 at 61,002 individuals. This increase can be attributed to security and climatic factors that have exacerbated living conditions in the affected areas. In 2022, a significant decline in the number of IDPs was observed, likely linked to enhanced humanitarian assistance initiatives and a temporary stabilization of security and political conditions in some areas of origin.

Simultaneously, the number of returnees from abroad and former IDPs has remained relatively stable, although these populations tend to gravitate towards host communities upon arrival.

According to data from the International Organization for Migration (IOM) [55] the average household size among displaced populations in the region is 6.5 persons. This demographic characteristic amplifies the demand for basic resources, as displaced households are generally larger than resident households. Furthermore, the concentration of displaced households in specific sites increases the demand for space, infrastructure, and services, posing additional challenges for local authorities and humanitarian organizations.

4.4. Identification of Space Needs Generated by the Humanitarian Crises in Bol

For a total population of IDPs in the Bol sub-prefecture:

Total IDPs = 45,729

Of these, 15% settle in the city:

IDPs Bol = 0.15 × Ptotal = 0.15 x 45,729 = 6,860

Assuming an average household size of 6.5 people in Bol, the total number of households is given by:

M = IDPs Bol / 6.5 = 6,860 / 6.5 = 11,055

Since each household requires a plot of 450 m^2, the total area of the plots is:

Sparcels = M × 450 = 11,055 x 450 = 45.7 ha

To ensure occupancy by urban planning regulations, an additional area of 35% is required for roads and various networks (VRD):

Svrd = 0.35 × Sparcelles = 0.35 x 25.6 ha = 25.6 ha

The total area required for the installation of the IDPs in Bol is, therefore:

Stotal = Sparcelles + VRD = 45.7 ha + 25.6 ha = 73.1 ha.

The results highlight a necessity of 73.1 ha to accommodate displaced persons due to humanitarian crises. Beyond land requirements, there is also a pressing need for socioeconomic infrastructure, housing, and income-generating activities to ensure sustainable integration and urban resilience.

5. Discussion

5.1. Urban Expansion Dynamics and Environmental Impacts in Bol

The rapid expansion of built-up areas in Bol between 1992 and 2016, marked by a 60.57% increase in land artificialization, reflects complex urban dynamics with significant environmental consequences. This evolution aligns with the findings of Bamba, et al. [56] who also reported rapid land cover changes in similar Sahelian urban contexts [56]. The expansion appears driven by demographic growth, economic pressures, and evolving land governance, resulting in the loss of natural habitats, heightened pollution, and altered hydrological systems. These results align with the findings of Hekmat, et al. [57] and Sikuzani, et al. [58]. These outcomes point to the increasing vulnerability of ecosystems under unregulated urbanization and call for the immediate adoption of sustainable urban management frameworks. Agricultural lands, essential to local food systems and livelihoods, have been particularly impacted. Their fragmentation and conversion to urban uses echo findings from studies in similar rural-urban transition zones by Gandapa [59] and Sylla, et al. [60]. Without integrated planning frameworks, this trend will likely worsen, reducing local populations' adaptive capacity and weakening the urban fringe's ecological buffers.

These effects underline the urgent need for sustainable land-use strategies that reconcile urban development with ecological preservation.

5.2. Displacement, Demographic Pressures, and Governance Gaps

Humanitarian crises and population displacement have compounded urban pressures in Bol. The influx of 6,860 internally displaced persons (IDPs) has intensified demand for shelter, services, and land, particularly in informal settlements shaped by proximity to aid and socio-cultural networks, as found by

Maynard, et al. [61]. With an average household size of 6.5 people, internally displaced persons (IDPs) would need approximately 73.1 hectares of land, putting additional pressure on already stretched urban infrastructure. These conditions highlight the urgent need for inclusive planning that takes into account the needs of displaced and vulnerable communities. Integrating geospatial tools into planning processes can help authorities manage spatial inequalities and improve decision-making. These results align with the findings of Xhafa and Kosovrasti [62] and Slimani and Raham [63]. Effective collaboration between municipal stakeholders and humanitarian actors is essential to ensuring coordinated responses and equitable land allocation.

The limited municipal capacities and weak coordination with humanitarian actors exacerbate spatial inequalities. Without formal planning instruments, informal settlements continue to expand on ecologically sensitive land. This governance deficit, largely unaddressed in the existing literature, is critical. Land tenure insecurity and the lack of clear urban zoning tools inhibit both emergency response and long-term urban development.

To move forward, Bol's urban governance must be strengthened. This includes formalizing land use plans, improving cadastral systems, and integrating displacement scenarios into municipal development strategies. Local authorities must also be empowered technically and institutionally to manage rapid urban growth in coordination with humanitarian stakeholders.

5.3. Towards Resilient Urban Development Strategies

The role of remote sensing and GIS is central in this context. These tools provide not only accurate diagnostics of land use dynamics but also decision-support capabilities for land allocation and risk assessment. The near-complete disappearance of wetlands (-94.33%) and the decline in agricultural zones should prompt immediate environmental protection efforts. Policy responses must go beyond technical monitoring. Bol needs a planning model that is both inclusive and flexible, one that puts ecological resilience at the forefront, prepares for sudden demographic changes caused by crises, and protects land rights for vulnerable populations in a fair and just way. To build lasting and legitimate solutions, urban planning should actively involve both host communities and displaced groups through participatory approaches. Finally, future research should focus on the operationalization of such planning frameworks. This includes assessing the role of traditional land governance systems, analyzing the socio-spatial integration of IDPs, and developing predictive spatial models to simulate future urban growth scenarios under different crisis and climate trajectories. Bridging spatial analysis with institutional and socio-economic data will be key to supporting effective and equitable policy design.

5.4. Perspectives for Sustainable Management and Urban Development

Geospatial technologies offer critical insights into land-use dynamics and inform evidence-based urban policy. The significant loss of wetlands (-94.33%) and marginal growth in water bodies (+9.01%) call for urgent environmental protection measures. Remote sensing and GIS, as demonstrated in the work of Braun [64] enable the continuous monitoring of these transformations and support the design of adaptive interventions [64].

Sandy soils and wetlands, key components of Bol's ecological resilience, require targeted policies that promote sustainable land and water management. This includes climate-adaptive agricultural practices and the protection of hydrological systems, as emphasized by Guo, et al. [65] and Vatsa, et al. [66]. Embedding such measures within a broader resilience-oriented planning strategy will enhance the city's capacity to withstand climate shocks and future humanitarian crises.
The findings underscore the intertwined challenges of environmental degradation and social vulnerability caused by rapid urban growth and displacement due to crises. To address these issues, Bol needs to embrace integrated and inclusive planning approaches that prioritize environmental protection, fair access to services, and long-term climate resilience. Future research should further explore community-based adaptation strategies, the role of traditional land governance systems, and the socio-

spatial integration of displaced populations. Quantitative analyses linking land-use dynamics with socioeconomic outcomes will also enhance the evidence base for policymaking.

6. Conclusions

This study analyzed the spatio-temporal transformations of the city of Bol and the role humanitarian crises play in shaping them, using a combination of satellite imagery, demographic data, and field observations. The results point to rapid and largely unplanned urban expansion, leading to the loss of key ecological zones such as agricultural land, sandy soils, and wetlands. These changes reflect a mounting tension between population growth driven partly by forced displacement and the city's limited planning capacity.

Despite the robustness of the methodological approach, several limitations must be acknowledged. The lack of detailed socio-economic data limits the ability to fully understand the lived impacts of land use change on vulnerable populations. Furthermore, the use of Landsat imagery, while appropriate for regional-scale analysis, presents spatial and temporal resolution constraints, particularly when capturing short-term or small-scale transformations. Future research should aim to integrate socio-economic surveys and participatory mapping to enrich the spatial analysis and improve the understanding of crisis-induced urban dynamics. Household-level data could provide valuable insight into displacement patterns, land tenure, and access to services. Additionally, predictive spatial models would allow for better anticipation of future urban growth scenarios. Comparing research from other Sahelian cities experiencing similar challenges would help develop planning strategies that are more tailored to the context, adaptable, and inclusive.

Funding:

This research and the APC were funded by the Regional Centre of Excellence on Sustainable Cities in Africa (CERViDA-DOUNEDON), the Association of African Universities (AAU), and the World Bank under the IDA 5360 TG number.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgments:

The authors would like to thank the Regional Centre of Excellence on Sustainable Cities in Africa (CERViDA-DOUNEDON) and the Association of African Universities for the administrative and technical support that made this research possible. We also thank NASA/USGS for freely providing Landsat-5, Landsat-7, and Landsat-8 data.

References

[1] D. P. Aldrich, O. Kolade, K. McMahon, and R. Smith, "Social capital's role in humanitarian crises," *Journal of Refugee Studies*, vol. 34, no. 2, pp. 1787-1809, 2021. https://doi.org/10.1093/jrs/feaa001

[2] K. Mitchell, R. Jones, and J. L. Fluri, *Handbook on critical geographies of migration.* Cheltenham, UK: Edward Elgar Publishing, 2019.

[3] OCHA Chad, "Humanitarian needs and response plan: Chad 2024. N'Djamena, Chad," Retrieved: https://www.unocha.org/publications/report/chad/tchad-besoins-humanitaires-et-plan-de-reponse-mars-2024, 2024.

[4] OIM Chad, *Chad: Displacement monitoring matrix (DTM), Lake Province - January 2024. N'Djamena.* Chad: Organisation Internationale de la Migration, 2024.
[5] World Bank, *World Bank open data.* . Washington, D.C: World Bank, 2023.
[6] M. H. Hassane, H. A. Mahamat, and T. B. Danvidé, "Analysis of the expansion of the city of N'Djamena in Chad (1900–2018)," *Geo-Eco-Trop*, vol. 45, pp. 507–516, 2021.
[7] PUR, *Reference urban plan for the town of Bol.* N'Djamena, Chad: Ministry of Urban Planning, 2011.
[8] Commune de Bol, *Communal development plan.* Bol, Chad: Municipality of Bol, 2020.
[9] S. K. Malhotra, M. Vigneri, N. A. O. D. Cruz, H. MacDonald, and H. White, "PROTOCOL: Effectiveness of economic development interventions in humanitarian settings in low-and middle-income countries: A mixed-method systematic review," *Campbell Systematic Reviews*, vol. 19, no. 4, p. e1357, 2023. https://doi.org/10.51744/cswp9
[10] J. Haas, "Remote sensing of urbanization and environmental impacts," Doctoral Dissertation, KTH Royal Institute of Technology, 2016.
[11] Y. Wang, G. Cai, L. Yang, N. Zhang, and M. Du, "Monitoring of urban ecological environment including air quality using satellite imagery," *Plos one*, vol. 17, no. 8, p. e0266759, 2022.
[12] S. Reis, "Analyzing land use/land cover changes using remote sensing and GIS in Rize, North-East Turkey," *Sensors*, vol. 8, no. 10, pp. 6188-6202, 2008. https://doi.org/10.3390/s8106188
[13] D. Furberg, "Satellie monitoring of urban growth and indicator-based assessment of environmental impact," Doctoral Dissertation, KTH Royal Institute of Technology, 2014.
[14] UNHCR, *Global trends: Forced displacement in 2022. Global trends: Forced displacement in 2022.* Geneva, Switzerland: United Nations High Commissioner for Refugees, 2022.
[15] Africa, *Centre for strategic studies: More than 40 million people displaced by conflict in Africa.* Amman, Jordan: Centre for Strategic Studies, 2023
[16] C. Wilson, "Spectral analysis of civil conflict-induced forced migration on land-use/land-cover change: The case of a primate and lower-ranked cities in Sierra Leone," *International Journal of Remote Sensing*, vol. 35, no. 3, pp. 1094-1125, 2014. https://doi.org/10.1080/01431161.2013.875633
[17] M. Géraud, "Crisis and development: The Lake Chad region put to the test by Boko Haram. Horizon," Retrieved: https://www.documentation.ird.fr/hor/fdi:010072290, 2018.
[18] J. K. Kataka, "On the absorption of displaced persons into host families in the cities of Beni and Butembo," *Parcours et Initiatives: Revue Interdisciplinaire Du Graben (PIRIG)*, vol. 21, pp. 27-44, 2023.
[19] Internal Displacement Monitoring Center, *Unsettlement: Urban displacement in the 21st century.* Geneva: Internal Displacement Monitoring Center, 2018.
[20] Global Network of Civil Society Organizations for Disaster Reduction, *Global report on forced displacement: Introduction and methodology.* London, UK: Global Network of Civil Society Organizations for Disaster Reduction, 2020.
[21] R. Sanyal, "Urbanizing refuge: Interrogating spaces of displacement," *International Journal of Urban and Regional Research*, vol. 38, no. 2, pp. 558-572, 2014. https://doi.org/10.1111/1468-2427.12020
[22] B. J. Jansen, "The protracted refugee camp and the consolidation of a 'humanitarian urbanism'," *International Journal of Urban and Regional Research*, 2016. https://doi.org/10.56949/2DLV7308
[23] R. E. Roberts and T. Lawanson, "Understanding IDPs in Nigerian cities," Researching Internal Displacement– Working Paper, No. (36), 2023.
[24] J. Steinberg, *A man of good hope.* New York: Knopf Doubleday Publishing Group, 2015.
[25] UNHCR, *UNHCR EHA handbook: Practical guide for refugee settings.* Geneva: United Nations High Commissioner for Refugees (UNHCR), 2020.
[26] S. Lang *et al.*, "Earth observation tools and services to increase the effectiveness of humanitarian assistance," *European Journal of Remote Sensing*, vol. 53, no. sup2, pp. 67-85, 2020. https://doi.org/10.1080/22797254.2019.1684208
[27] Global Alliance for Urban Crises, *Adapting global crisis response to an urban world.* London: Global Alliance for Urban Crises, 2016.
[28] UN HABITAT, *Monitoring and evaluation of national urban policy - urban policy platform.* Nairobi: UN HABITAT, 2020.
[29] D. Archer and D. Dodman, "The urbanization of humanitarian crises," *Environment and Urbanization*, vol. 29, no. 2, pp. 339-348, 2017.
[30] F. Bachofer, G. Quénéhervé, T. Zwiener, M. Maerker, and V. Hochschild, "Comparative analysis of edge detection techniques for SAR images," *European Journal of Remote Sensing*, vol. 49, no. 1, pp. 205-224, 2016.
[31] M. Bouziani, K. Goita, and D.-C. He, "Rule-based classification of a very high resolution image in an urban environment using multispectral segmentation guided by cartographic data," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 48, no. 8, pp. 3198-3211, 2010.
[32] M. Dadras, H. Z. Shafri, N. Ahmad, B. Pradhan, and S. Safarpour, "Spatio-temporal analysis of urban growth from remote sensing data in Bandar Abbas city, Iran," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 18, no. 1, pp. 35-52, 2015.
[33] V. Abbas, K. Z. Ebrahimi, M. Khosroshahi, and R. Ghazavi, "Land use change detection using GIS and RS techniques casestudy: The South east of Zayanderood Basin, Esfahan," *Iran Journal of Biodiversity and Environmental Sciences*, vol. 8, pp. 20166663–2222 2016

ISSN: 2576-8484
Vol. 9, No. 5: 2923-2939, 2025
DOI: 10.55214/25768484.v9i5.7617

[34] A.-m. A. Agidew and K. Singh, "The implications of land use and land cover changes for rural household food insecurity in the Northeastern highlands of Ethiopia: the case of the Teleyayen sub-watershed," *Agriculture & Food Security*, vol. 6, pp. 1-14, 2017.
[35] M. Baumann, V. C. Radeloff, V. Avedian, and T. Kuemmerle, "Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict," *Regional Environmental Change*, vol. 15, pp. 1703-1716, 2015.
[36] V. Butsic, M. Baumann, A. Shortland, S. Walker, and T. Kuemmerle, "Conservation and conflict in the Democratic Republic of Congo: The impacts of warfare, mining, and protected areas on deforestation," *Biological conservation*, vol. 191, pp. 266-273, 2015.
[37] Y. Hu, Q. Zhang, Y. Zhang, and H. Yan, "A deep convolution neural network method for land cover mapping: A case study of Qinhuangdao, China," *Remote Sensing*, vol. 10, no. 12, p. 2053, 2018.
[38] M. Sheikh and P. Defourny, "Assessing cropland abandonment in rural conflict areas using satellite imagery in humanitarian contexts," Doctoral Dissertation, University of Copenhagen, 2023.
[39] J. Van Den Hoek and H. K. Friedrich, "Satellite-based human settlement datasets inadequately detect refugee settlements: a critical assessment at thirty refugee settlements in Uganda," *Remote Sensing*, vol. 13, no. 18, p. 3574, 2021.
[40] S. Lang, P. Füreder, and E. Rogenhofer, "Earth observation for humanitarian operations," *Yearbook on Space Policy 2016: Space for Sustainable Development*, pp. 217-229, 2018.
[41] P. Hardy, *Multi-scale cartography: Maps, tools and models*. Germany: Springer Science & Business Media, 2012.
[42] H. D. a. U. P. Ministry of Regional Planning, *National regional planning scheme (2014-2035)*. Kenya: Ministry of Regional Planning, 2014.
[43] C. Atuhaire, A. Gidudu, E. Bainomugisha, and A. Mazimwe, "Determination of satellite-derived PM2. 5 for Kampala District, Uganda," *Geomatics*, vol. 2, no. 1, pp. 125-143, 2022. https://doi.org/10.3390/geomatics2010008
[44] I. Diédhiou, C. Mering, O. Sy, and T. Sané, "Mapping land use and its changes using remote sensing, Application to the analysis of the dynamics of Senegambian forest landscapes between 1972 and 2016," *EchoGéo*, vol. 54, pp. 1-10, 2020.
[45] Y. Guo *et al.*, "Dark-object subtraction atmosphere correction for water body information extraction in Zhuhai-1 hyperspectral imagery," *The Egyptian Journal of Remote Sensing and Space Sciences*, vol. 27, no. 2, pp. 382-391, 2024. https://doi.org/10.1016/j.ejrs.2024.04.007
[46] S. Gilmore, A. Saleem, and A. Dewan, "Effectiveness of DOS (Dark-Object Subtraction) method and water index techniques to map wetlands in a rapidly urbanising megacity with Landsat 8 data," Retrieved: https://www.researchgate.net/publication/281667599_Effectiveness_of_DOS_Dark-Oject_Subtraction_method_and_water_index_techniques_to_map_wetlands_in_a_rapidly_urbanising_megacity_with_Landsat_8_data, 2015
[47] Q.-G. Shao, J. J. Liou, S.-S. Weng, and P. Su, "Constructing an entrepreneurship project evaluation system using a hybrid model," *Journal of Business Economics and Management*, vol. 21, no. 5, pp. 1329-1349, 2020.
[48] A. E. Garouani and K. Aharik, "Contribution of LANDSAT images to the study of the evolution of land use in the SAÏSS plain in MOROCCO, for the period 1987-2018," *French Journal of Photogrammetry and Remote Sensing*, vol. 223, pp. 173–88 2021
[49] I. Achir, H. Mohamed, A. Rachid, and A. Fellak, "Relation between night-time surface temperature and land cover: cartographic study based on aster satellite images, case of the city of demarrakech and its periphery (MOROCCO) 11/12 33–9 " *Espaces*, vol. 11-12, pp. 33-39, 2024.
[50] G. Sallé, *Low-speed generative learning of data for image segmentation in oncology PhD*. University of Western Brittany - Brest, 2024
[51] F. Scalvini, "Method and system for assisting people in navigation based on the sound perception of a visual scene PhD," UBFC - University of Burgundy Franche, 2024
[52] H. S. Shah and G. Mountrakis, "Optimizing spatial-spectral-temporal neural network models for large-scale landcover classification based on landsat data archive," presented at the AGU Fall Meeting Abstracts, 2020.
[53] J. Cohen, "A coefficient of agreement for nominal scales," *Educational and Psychological Measurement*, vol. 20, no. 1, pp. 37-46, 1960. https://doi.org/10.1177/001316446002000104
[54] M. L. McHugh, "Interrater reliability: The kappa statistic," *Biochemia Medica*, vol. 22, no. 3, pp. 276-282, 2012.
[55] International Organization for Migration (IOM), *Displacement tracking matrix: Annual report 2018*. Switzerland: International Organization for Migration, 2018.
[56] I. Bamba *et al.*, "Influence of anthropogenic actions on the spatio-temporal dynamics of land use in the province of Bas-Congo (DR Congo)," *Sciences & Nature*, vol. 5, no. 1, pp. 49-60, 2008.
[57] H. Hekmat, T. Ahmad, S. K. Singh, S. Kanga, G. Meraj, and P. Kumar, "Land use and land cover changes in Kabul, Afghanistan focusing on the drivers impacting urban dynamics during five decades 1973–2020," *Geomatics*, vol. 3, no. 3, pp. 447-464, 2023. https://doi.org/10.3390/geomatics3030024
[58] Y. U. Sikuzani, S. Boisson, S. C. Kaleba, and C. N. Khonde, "Land cover dynamics around mining sites along urban-rural gradient of Lubumbashi city (DR Congo)," *Environmental Monitoring and Assessment*, vol. 192, no. 7, pp. 1-12, 2020.

[59] E. Gandapa, "Spatio-temporal change detection of land-use land cover of Hong Local Government Area, Adamawa State, Nigeria," *ATBU Journal of Environmental Technology*, vol. 11, no. 1, pp. 41-54, 2018.

[60] D. Sylla, T. Ba, D. M. Dalanda, and T. Mbaye, "Dynamics of the land occupation of the municipality of Téssékéré from 1984 to 2015 (Ferlo Nord, Senegal)," *Journal of Animal and Plant Sciences* pp. 4087–9674, 2019 https://doi.org/10.35759/JAnmPlSci.v40-3.2

[61] V. Maynard, E. Parker, R. Yoseph-Paulus, and D. Garcia, "Urban planning following humanitarian crises: supporting urban communities and local governments to take the lead," *Environment and Urbanization*, vol. 30, no. 1, pp. 265-282, 2018.

[62] S. Xhafa and A. Kosovrasti, "Geographic information systems (GIS) in urban planning," *European Journal of Interdisciplinary Studies*, vol. 1, no. 1, pp. 74-81, 2015. https://doi.org/10.26417/ejis.v1i1.p85-92

[63] N. Slimani and D. Raham, "Urban growth analysis using remote sensing and gis techniques to support decision-making in algeria—the case of the city of setif," *Journal of the Geographical Institute "Jovan Cvijić" SASA*, vol. 73, no. 1, pp. 17–32, 2023. https://doi.org/10.2298/IJGI2301017S

[64] A. Braun, "Radar satellite imagery for humanitarian response. Bridging the gap between technology and application," Doctoral Dissertation, Universität Tübingen, 2019.

[65] S. Guo, Y. Yang, and P. Guo, "An integrated distributed robust optimization framework for agricultural water-food-energy management integrating ecological impact and dynamic water cycle processes," *Journal of Hydrology*, 2023 https://doi.org/10.3390/su132011170

[66] P. Vatsa, W. Ma, H. Zheng, and J. Li, "Climate-smart agricultural practices for promoting sustainable agrifood production: Yield impacts and implications for food security," *Food Policy*, pp. 1-10, 2023 https://doi.org/10.11613/BM.2012.031