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ASSESSMENT OF CLIMATE CHANGE TRENDS IN ADIYAMAN PROVINCE, TÜRKİYE

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Abstract: Factors affecting climate formation are examined in two main categories: natural and anthropogenic factors. Natural factors include atmospheric composition, solar radiation, topographic structure, and ocean circulation, while anthropogenic factors encompass industrial activities, energy production, agricultural practices, deforestation, and urban expansion. In this study, climate trend analyses were conducted for Adiyaman province located in the Southeastern Anatolia Region. In this context, trend analyses were performed on annual extreme temperature data obtained from meteorological stations in Adiyaman center, Kahta, and Gölbaşı for the period 1993-2022. Non-parametric statistical methods (Mann-Kendall test and Sen's slope estimator) were used for trend analyses. Research findings revealed statistically significant increases in maximum and minimum temperature values in the Adiyaman region. Trend analyses demonstrated that temperature values in the region showed an upward trend and the frequency of extreme temperature events increased. In conclusion, this research has revealed the sensitivity of the Adiyaman region to climate change and the effects of temperature increases with scientific data. The results constitute an important scientific resource for understanding regional climate variability, predicting future climate trends, and developing climate change mitigation strategies.

Keywords: Climate change, Trend analysis, Mann-Kendall, Sen's slope, Extreme temperature, Adiyaman

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1. Introduction

Climate change represents one of the most critical contemporary challenges, generating profound environmental, economic, and social consequences on a global scale. The climate system is governed by both natural forcings (atmospheric composition, solar radiation, topography, and ocean circulation patterns) and anthropogenic drivers (industrial processes, energy production, agricultural practices, deforestation, and urbanization). Over the past century, the intensification of anthropogenic influences has led to significant increases in mean global temperatures, resulting in substantial alterations to regional climate patterns and increased frequency of extreme weather events.

Türkiye exhibits enhanced vulnerability to climate change impacts due to its geographical location at the intersection of multiple climate zones and its complex topographic features. The Southeastern Anatolia Region is particularly susceptible, characterized by semi-arid climate conditions, rapid urbanization, and intensive agricultural land use. Recent research demonstrates that this region is experiencing pronounced warming trends

and increasing drought severity. Erhat and Güler (2018) analyzed temporal variations in extreme temperature events across Turkey during 1950-2017, identifying the most significant reduction in cold period duration within the Southeastern Anatolia Region. Acar-Deniz and Gönençgil (2017) documented statistically significant increases in extreme hot day frequencies nationwide, while Turgu and Kömüşçü (2011) detected accelerating drought trends in Southeastern Anatolia using Mann-Kendall trend analysis. In the Southeastern Anatolia region, Kartal et al. (2024) analyzed long-term meteorological data from three stations (1981-2022) using the Mann-Kendall test, Sen's slope estimator, and innovative trend analysis, identifying a declining precipitation trend coupled with increasing drought severity since 1996. Their findings using multiple drought indices (SPI, SPEI, CZI, and EDI) demonstrated that the region's water resources and agricultural activities face growing pressure from climate change. Temperature trend variations in Adiyaman province have generated considerable impacts on critical sectors, particularly agriculture and water resource management.



statistic. Assuming that the sample is drawn from a population with a normal distribution, the sampling distribution of the test statistic follows a chi-square distribution with $n - 1$ degrees of freedom, where n denotes the sample size (Walpole et al., 2012).

For a two-tailed test, critical values are obtained from the chi-square distribution table and compared with the calculated test statistic. If the test statistic falls within the acceptance region, the null hypothesis (H_0) is accepted;

otherwise, it is rejected. For one-tailed tests, the acceptance region is determined based on whether the alternative hypothesis specifies that the population variance is less than or greater than the hypothesized value. A left-tailed test is applied when testing whether the variance is less than the specified value, whereas a right-tailed test is used when testing whether the variance is greater than the specified value (Montgomery and Runger, 2014).

Table 1. Information on the stations.

	Station name	Station No	Altitude (m)	Latitude (North)	Longitude (East)	Measurement Range
1.	Adıyaman	17265	672	37° 45' 00.0"	38° 17' 00.0"	1993-2022
2.	Kahta	17910	675	37° 47' 00.0"	38° 37' 00.0"	1993-2022
3.	Gölbaşı	17871	900	37° 47' 00.0"	37° 38' 00.0"	1993-2002

2.5. Mann-Kendall Test

The Mann-Kendall test is a statistical test used to determine the presence and direction of trends in a data set. This test is employed to identify whether the values in a data set exhibit an increasing or decreasing trend and is a non-parametric test; therefore, it does not require the assumption of normal distribution. The Mann-Kendall test is a frequently utilized analysis for detecting trends in hydro-meteorological time series (Hirsch, et al., 1982; Yue et al., 2002).

The Mann-Kendall S test statistic is calculated as shown in equation (1) below.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_i) \tag{1}$$

where n is the total number of data points, x_i and x_j are the data points at times i and j , respectively, and $j > i$. Sgn is the sign function and is calculated as shown in equation (2).

$$\text{gn}(x_j - x_i) = \begin{cases} +1 & \text{If } (x_j - x_i) > 0 \\ 0 & \text{If } (x_j - x_i) = 0 \\ -1 & \text{If } (x_j - x_i) < 0 \end{cases} \tag{2}$$

The variance of S is determined by the following equation.

$$\text{Var}(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^m t(t-1)(2t+5)]}{18} \tag{3}$$

In equation (3), m represents the total number of equal numbers, and t represents the number of equal data points. Using the test statistic Z value, S from equation 1 and Var(S) from equation (3), equation (4) is obtained:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{If } S > 0 \\ 0 & \text{If } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{If } S < 0 \end{cases} \tag{4}$$

A positive Z value indicates an increasing trend, while a negative value indicates a decreasing trend (Gilbert, 1987; Helsel and Hirsch, 2002).

2.6. Sen’s Slope Estimator

When a linear trend exists within a time series, Sen's slope estimator is used to estimate the actual trend. It is a non-parametric method and can be applied in cases

where the trend can be assumed to be linear (Salmi et al., 2002). This method calculates the slope for all pairs of ordered data values and uses the median of these slopes to determine the trend line. This line represents the magnitude and direction of the trend in the data set. The linear model $f(t) = Q_t + B$ is expressed as:

where x_j and x_k are the data at times j and k (provided $j > k$).

$$N = \frac{n(n-1)}{2} \tag{5}$$

n : represents time periods. The value of Q_i ($i = 1, 2, \dots, n$) is expressed by the equation in (6).

$$Q_i = \frac{(x_j - x_k)}{j - k} \quad (j = 1, 2, \dots, N) \tag{6}$$

The obtained Q_i values are sorted from smallest to largest. The median of N Q_i values estimates Sen's linear slope parameter. If the number N is odd, (7) is used; if it is even, (8) is used:

$$Q = \frac{Q_{N+1}}{2} \tag{7}$$

$$Q = \left\{ \frac{1}{2} \left[Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}} \right] \right\} \tag{8}$$

3. Results and Discussions

3.1. Evaluation of Temperature

Upon examination of the temporal graphs illustrating the monthly and annual maximum, minimum, and mean temperature values for the Adıyaman station, it is evident that temperature values exhibit clear variability across both months and years (Figures 2-4). At the Adıyaman station, maximum mean temperature values reach their highest levels during May and July, approaching 40 °C. In contrast, temperatures decrease during the autumn and winter seasons, with the lowest maximum values observed in December and January. Minimum mean temperature values attain their lowest levels in January and February and gradually increase toward the summer months. Mean temperature values peak during the summer season, with June, July, and August representing the warmest period of the year. Conversely, the mean temperatures decline during the winter months.

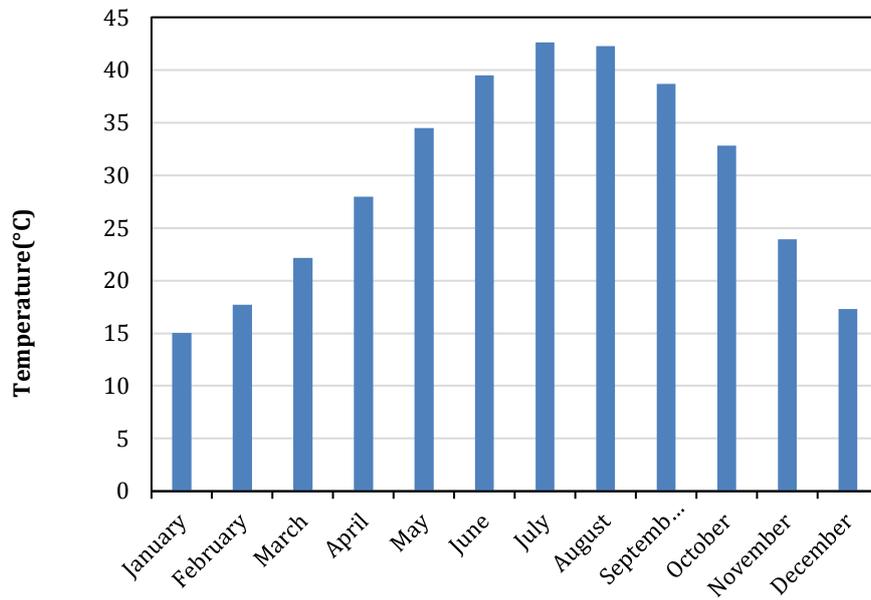


Figure 2. Monthly mean maximum temperature distribution at Adiyaman station.

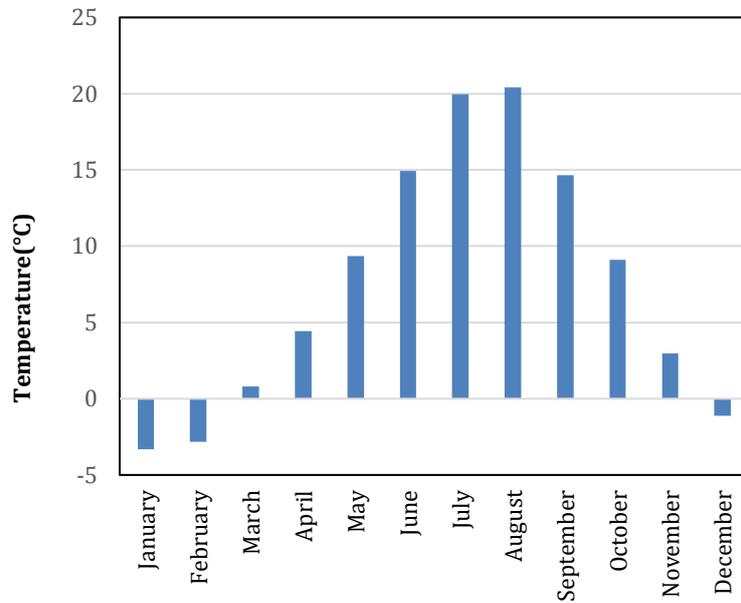


Figure 3. Monthly mean minimum temperature distribution at Adiyaman station.

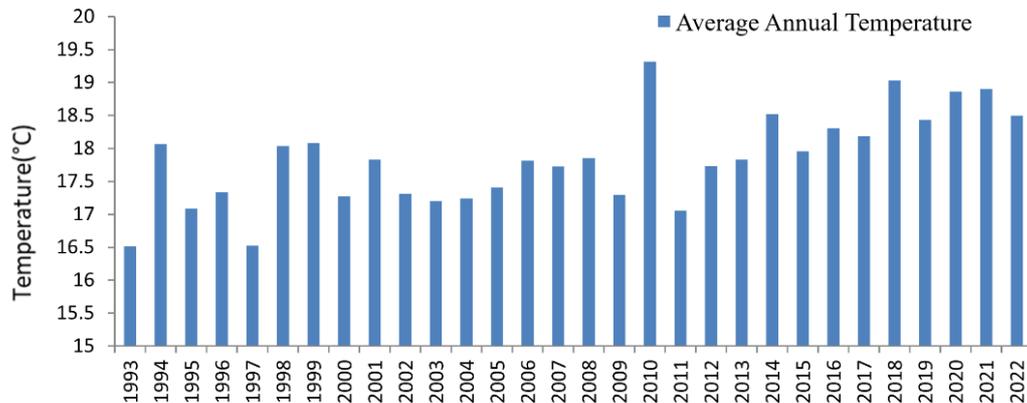


Figure 4. Mean annual temperature distribution at Adiyaman station

3.2. Homogeneity Test Results for Temperature

According to the homogeneity test results for mean temperatures at the Adiyaman station, the analysis was conducted monthly and subsequently on an annual basis. Data with a p-value equal to or greater than 0.05 were considered homogeneous, indicating that no statistically significant change was detected. In contrast, data with a p-value below 0.05 were classified as non-homogeneous, suggesting the presence of a statistically significant change. Overall, the results indicate that the mean temperature data at the Adiyaman station are not homogeneous (Figure 5).

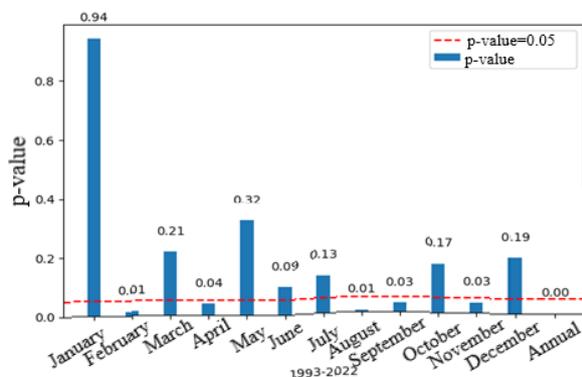
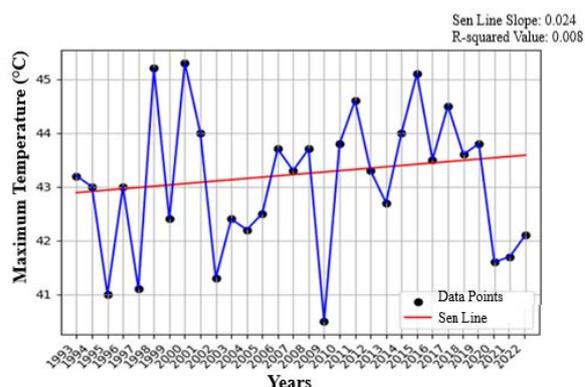


Figure 5. Homogeneity test results for the mean temperature values at the Adiyaman station.

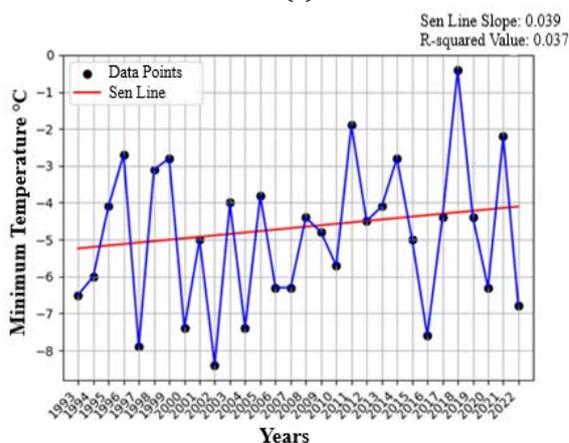
3.3. Sen's Slope-Based Trend Analysis Results

An examination of the trend graphs representing annual maximum, minimum, and mean temperature values for Adiyaman Province indicates a continuous increase in temperature on an annual basis. At the Adiyaman station, temperature values clearly exhibit interannual variability. The trend graphs illustrate seasonal variations, the direction and magnitude of temperature changes, and differences between years (Figure 6). Sen's slope trend analysis conducted for the Adiyaman station reveals a positive trend in annual temperature records. The slope value for annual maximum temperature was calculated as 0.024, while the slope for annual minimum temperature was 0.039. For the annual mean temperature, the Sen's slope value was determined to be 0.059, indicating a pronounced increasing temperature trend over the study period.

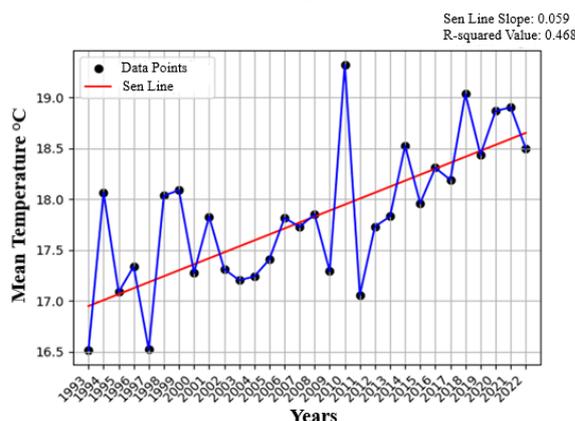
The climatological analysis of temperature parameters at Adiyaman Station over the 1993-2022 period reveals distinct thermal characteristics. Annual maximum temperature extremes exhibit a range of 4.8°C, with values spanning from 40.5°C to 45.3°C and a mean temperature of 43.07°C. The relatively low standard deviation ($\sigma = 1.276$) indicates minimal interannual variability in extreme maximum temperatures, while the slightly negative skewness coefficient (-0.150) suggests a near-normal distribution with a marginal left-tail tendency (Table 2).



(a)



(b)



(c)

Figure 6. Annual temperature trends at the Adiyaman station based on Sen's slope analysis: (a) maximum temperature, (b) minimum temperature, and (c) mean temperature.

Annual minimum temperature extremes demonstrate substantially greater variability, with a thermal range of 8.0°C extending from -8.4°C to -0.4°C and a climatological mean of -4.84°C. The higher standard deviation ($\sigma = 1.956$) relative to maximum temperatures indicates enhanced interannual fluctuations in cold extremes. The positive skewness coefficient (0.293) reveals a right-skewed distribution, indicating a tendency toward milder winter minimum temperatures during the study period. Mean annual temperature values range from 16.5°C to 19.3°C, with a 30-year climatological normal of 17.84°C.

This parameter exhibits the lowest temporal variability, as evidenced by the minimal standard deviation ($\sigma = 0.703$) and variance ($\sigma^2 = 0.494$). The weakly positive

skewness coefficient (0.153) indicates an approximately symmetrical distribution with a slight bias toward warmer years (Table 2).

Table 2. Temperature parameters and statistical values obtained from annual data for the 1993-2022 period at Adiyaman station

Parameter	Minimum Value	Maximum Value	Mean (μ)	Variance (σ^2)	Standard Deviation (σ)	Skewness Coefficient
Max. Temperature	40.5	45.3	43.07	1.628	1.276	-0.150
Min. Temperature	-8.4	-0.4	-4.84	3.828	1.956	0.293
Mean Temperature	16.5	19.3	17.84	0.494	0.703	0.153

3.5. Mann-Kendall Trend Analysis Results

The Mann-Kendall trend analysis conducted for Adiyaman Station over the 1993-2022 period reveals statistically significant positive trends in all temperature parameters (Table 3.2.). The null hypothesis (H_0) of no trend was evaluated at two significance levels ($\alpha = 0.10$ and $\alpha = 0.05$). For maximum temperature, the Mann-Kendall test statistic ($S = 41$) yielded a standardized Z value of 0.71 (Table 3.2.). While this value does not exceed the critical threshold at either the 90% ($Z = \pm 1.645$) or 95% ($Z = \pm 1.96$) confidence levels, the positive S statistic indicates an upward tendency in annual maximum temperature extremes, though the trend is not statistically significant at significance levels. Minimum temperature exhibited a similar pattern, with a test statistic of $S = 45$ and a calculated Z value of 0.79. This value also falls below the critical thresholds, indicating a positive but statistically non-significant trend in annual minimum temperature extremes at the $\alpha = 0.05$ and $\alpha = 0.10$ levels. Mean annual temperature demonstrated the strongest and most statistically significant trend, with a Mann-Kendall statistic of $S = 215$ and a highly significant Z value of 3.82. This value substantially exceeds both critical thresholds ($\alpha = 0.10$

and $\alpha = 0.05$), leading to the acceptance of the alternative hypothesis (H_1) and confirming the presence of a statistically significant increasing trend in mean annual temperature at the 95% confidence level ($p < 0.05$). The magnitude of the Z statistic (3.82) indicates a robust and persistent warming trend in the baseline climatic conditions at Adiyaman Station during the 30-year study period (Table 3). All three temperature parameters exhibit upward trends (▲), consistent with regional warming patterns associated with anthropogenic climate change in the Eastern Mediterranean region. The findings of this study are in agreement with Kartal (2024), who identified a statistically significant increasing trend in mean annual temperature at Adiyaman Station, reflecting a clear regional warming signal. Consistent with this warming trend, our results indicate a general decrease in precipitation and an increase in drought frequency and severity across Southeastern Anatolia since the mid-1990s. Together, these results confirm that rising temperatures, coupled with changing precipitation patterns, are intensifying drought risk and increasing pressure on regional water resources and agricultural activities, in line with the conclusions of Kartal (2024).

Table 3. Mann-Kendall test results and trend analysis based on annual data for the 1993-2022 period at Adiyaman station

Parameter	MK Test Statistic (S)	Calculated Z Values	Critical Z Value ($\alpha=0.10$)	Critical Z Value ($\alpha=0.05$)	H_0 Hypothesis	Trend Present/Absent	Trend
Max. Temperature	41	0.71	± 1.645	± 1.96	Rejected	Present	▲
Min. Temperature	45	0.79	± 1.645	± 1.96	Rejected	Present	▲
Mean Temperature	215	3.82	± 1.645	± 1.96	Accepted	Present	▲

4. Conclusion

This study assessed climate change trends in Adiyaman Province, Turkey, through a comprehensive statistical

analysis of temperature data spanning the 1993-2022 period. The Mann-Kendall trend test and Sen's slope estimator were employed to detect and quantify

temporal trends in annual maximum, minimum, and mean temperature parameters. The climatological analysis of Adiyaman Station revealed distinct thermal characteristics across different temperature metrics. Maximum temperature values exhibited a range from 40.5°C to 45.3°C with a climatological mean of 43.07°C, while minimum temperatures ranged from -8.4°C to -0.4°C with a mean of -4.84°C. Mean annual temperatures varied between 16.5°C and 19.3°C, with an overall climatological normal of 17.84°C. The relatively low standard deviation ($\sigma = 0.703$) in mean temperature suggests baseline climatic stability during the study period.

The Mann-Kendall trend analysis demonstrated statistically significant evidence of warming trends across all temperature parameters at Adiyaman Station. While maximum temperature ($S = 41, Z = 0.71$) and minimum temperature ($S = 45, Z = 0.79$) exhibited positive trends that did not reach statistical significance at confidence levels ($\alpha = 0.05$ or $\alpha = 0.10$), mean annual temperature showed a highly significant increasing trend ($S = 215, Z = 3.82, p < 0.05$). The calculated Z value of 3.82 substantially exceeded both critical thresholds, confirming a warming trend at the 95% confidence level. Sen's slope analysis quantified the magnitude of the temperature trend, revealing an increasing rate of 0.059°C per year for mean annual temperature. This warming rate translates to an approximate temperature increase of 1.77°C over the 30-year study period, demonstrating substantial climatic change in the region. The significant upward trend in mean annual temperature, coupled with positive tendencies in both maximum and minimum extremes, suggests that Adiyaman Province is experiencing measurable impacts of climate change.

The implications of these warming trends are considerable for the region. Rising temperatures may influence agricultural productivity, water resource availability, energy demand patterns, and ecosystem dynamics. The increase in temperature extremes could exacerbate heat stress conditions during summer months, potentially affecting human health and socioeconomic activities. Additionally, changes in thermal regimes may alter hydrological processes, including evapotranspiration rates and soil moisture dynamics, with cascading effects on regional water security.

These findings underscore the necessity for climate adaptation strategies tailored to Adiyaman Province. Local authorities should integrate these trends into long-term planning for water management, agriculture, urban development, and public health. Further research on precipitation patterns, extreme events, and drought indices is recommended for a comprehensive understanding of regional climate impacts. The methodological approach employed in this study, combining non-parametric statistical tests with trend magnitude estimation, proved effective for detecting and

quantifying climate trends in the absence of normally distributed data. This framework can be applied to other meteorological stations across Turkey to develop a comprehensive assessment of regional climate change patterns and inform evidence-based climate policy and adaptation measures.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	S.A	M.Ş.Ö	B.E.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	30	30
DAI	40	30	30
L	40	30	30
W	40	30	30
CR	40	30	30
SR	40	30	30
PM	40	30	30
FA	40	30	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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DÖNÜŞTÜRÜLEBİLİR ATIKLARIN ÇOCUK SAĞLIĞINA ETKİLERİ

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Özet: Çocuklar, hızlı fizyolojik gelişimleri, yüksek solunum hızları, elden ağıza davranışları ve olgunlaşmamış detoksifikasyon sistemleri nedeniyle çevresel maruziyetler açısından en savunmasız nüfus gruplarından birini temsil etmektedir. Plastik, metal, kağıt, cam ve elektronik malzemeler gibi geri dönüştürülebilir atıkların uygunsuz yönetimi, çocukların solunum sağlığını, cilt bütünlüğünü, nörogelişimini ve genel refahını olumsuz etkileyebilecek çok sayıda çevresel risk oluşturmaktadır. Bu araştırma, geri dönüştürülebilir atıkların sağlık üzerindeki etkileri, çocukların çevre bilinci ve eğitim programlarının çevresel riskleri azaltmadaki rolü hakkındaki güncel ulusal literatürü sentezlemeyi amaçlamaktadır. 2017-2024 yılları arasında TR Dizin, DergiPark ve açık erişimli üniversite veritabanları kullanılarak bir literatür taraması yapılmıştır. Anahtar kelimeler arasında "geri dönüşüm", "çocuk sağlığı", "çevre bilinci" ve "atık yönetimi" yer almaktadır. Bulgular, yönetilmeyen atıklardan kaynaklanan hava kirlenmelerine maruz kalmanın çocuklarda astım, alerjik reaksiyonlar, kronik öksürük ve göz tahrişi prevalansını artırdığını göstermektedir. Ayrıca, yanlış yönetilen elektronik atıklar, dikkat eksikliği ve nörobilişsel gelişim bozukluğuyla ilişkilendirilen ağır metal maruziyetine yol açmaktadır. Bir diğer önemli bulgu ise, yapılandırılmış eğitim programlarının, proje tabanlı öğrenme etkinliklerinin ve aile katılımının çocukların çevre bilgisi, tutumları ve sürdürülebilir davranışlarını geliştirmede önemli roller oynadığıdır. "Sıfır Atık Projesi" gibi ulusal girişimler farkındalığı artırmada etkili olmuştur; ancak uygulama kurumlar arasında farklılık göstermektedir. Bu inceleme, sürdürülebilir atık yönetimini teşvik etmek ve çocuk sağlığını korumak için entegre okul-aile-toplum işbirliğine duyulan ihtiyacı vurgulamaktadır. Çevre bilincini güçlendirmek ve atıkla ilgili sağlık risklerini azaltmak için eğitimciler, politika yapımcılar ve aileler için öneriler sunulmaktadır.

Anahtar kelimeler: Çocuk sağlığı, Çevre bilinci, Geri dönüşüm, Sıfır atık, Atık yönetimi

The Effects of Recyclable Waste on Children's Health

Abstract: Children represent one of the most vulnerable population groups regarding environmental exposures due to their rapid physiological development, higher respiratory rates, hand-to-mouth behaviors, and immature detoxification systems. Improper management of recyclable waste—such as plastics, metals, paper, glass, and electronic materials—creates multiple environmental risks that may negatively affect children's respiratory health, skin integrity, neurodevelopment, and overall well-being. This study aims to synthesize current national literature on the health effects of recyclable waste, children's environmental awareness, and the role of educational programs in reducing environmental risks. A literature search was conducted using TR Dizin, DergiPark and open-access university databases between 2017 and 2024. Keywords included "recycling," "child health," "environmental awareness," and "waste management." Findings indicate that exposure to air pollutants from unmanaged waste increases the prevalence of asthma, allergic reactions, chronic cough, and eye irritation among children. Additionally, mismanaged electronic waste leads to heavy metal exposure, which has been associated with attention deficits and impaired neurocognitive development. Another important finding is that structured educational programs, project-based learning activities, and family involvement play significant roles in improving children's environmental knowledge, attitudes, and sustainable behaviors. National initiatives such as the "Zero Waste Project" have been effective in raising awareness; however, implementation varies across institutions. This study highlights the need for integrated school-family-community collaboration to promote sustainable waste management and protect child health. Recommendations for educators, policymakers, and families are provided to strengthen environmental awareness and reduce waste-related health risks.

Keywords: Child health, Environmental awareness, Recycling, Zero waste, Waste management

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1. Giriş

Günümüzde hızlı nüfus artışı, tüketim alışkanlıklarının değişmesi ve teknolojik gelişmeler, atık miktarında dramatik bir artışa yol açmaktadır (UNEP, 2023). Birleşmiş Milletler Çevre Programı'na göre dünyada yıllık 11 milyar tondan fazla atık üretilmekte; bunun önemli bir

kısmı dönüştürülebilir olmasına rağmen uygun şekilde yönetilememektedir (UNEP, 2023). Türkiye'de ise evsel ve endüstriyel atıkların yıllık miktarı yaklaşık 30 milyon ton civarındadır ve özellikle plastik, elektronik ve ambalaj atıkları hızla artmaktadır (Taşan, 2024). Bu durum hem çevresel sürdürülebilirliği hem de toplum



sağlığını tehdit etmektedir (Bayraktar ve Fırat, 2020). Çocuklar, gelişimsel özellikleri gereği çevresel kirlenmelere karşı daha savunmasızdır (WHO, 2022). Dünya Sağlık Örgütü (WHO), çocukların toksik maddelere yetişkinlere oranla 3-5 kat daha duyarlı olduğunu belirtmektedir (WHO, 2022). Solunum sistemlerinin tam gelişmemiş olması, deri yüzeylerinin vücut hacmine oranla daha geniş olması ve el-ağız temasının fazla olması, çevresel risklere maruziyeti artırmaktadır (WHO, 2022). Sürdürülebilir çevre davranışlarının kazanılması için en kritik dönem çocukluk dönemidir (Tümer, 2017). Literatür, çocuklara verilen geri dönüşüm ve çevre eğitiminin uzun vadede çevresel sorumluluk bilincini artırdığını göstermektedir (Kazu ve Yapıcı Ödemiş, 2023). Türkiye’de uygulanan “Sıfır Atık Projesi” bu açıdan önemli bir gelişme yaratmıştır (Taşan, 2024). Bu çalışmanın amacı, dönüştürülebilir atıkların çocuk sağlığına etkilerini, çocuklarda çevresel farkındalık gelişimini ve eğitim programlarının etkinliğini geniş kapsamlı ulusal literatür doğrultusunda incelemektir.

2. Materyal ve Yöntem

Bu çalışma nitel bir literatür araştırması olarak tasarlanmıştır (Taşan, 2024). Araştırma 2017-2024 yılları arasında yayımlanan Türkçe akademik makaleleri kapsamıştır (Kazu ve Yapıcı Ödemiş, 2023). Veri toplama sürecinde Google akademik, TR Dizin, DergiPark, YÖK Ulusal Tez Merkezi ve üniversitelerin açık erişim kaynakları taranmıştır (Taşan, 2024).

2.1. Arama Stratejisi

Literatür taraması aşağıdaki anahtar kelimeler kullanılarak gerçekleştirilmiştir:

“geri dönüşüm, çocuk sağlığı, çevresel farkındalık, atık yönetimi, sıfır atık, elektronik atık.”

Yapılan taramalar sonucunda 40’ın üzerinde çalışmaya ulaşılmıştır. Başlık ve özet incelemesi sonrasında konu dışı ve yinelenen yayınlar elenmiş, yaklaşık 25-30 çalışma tam metin değerlendirmesine alınmıştır. Dahil etme ve dışlama kriterleri uygulandıktan sonra 18 çalışma literatür araştırmasına dahil edilmiştir.

2.2. Literatür Tarama Süreci

Literatür tarama süreci aşağıdaki aşamalardan oluşmuştur:

1. İlgili veri tabanlarında anahtar kelime taraması
2. Yinelenen çalışmaların çıkarılması
3. Başlık ve özet incelemesi
4. Tam metin değerlendirmesi
5. Dahil etme ve dışlama kriterlerine göre son seçimin yapılması

Bu süreç, literatür taramasının şeffaf ve sistematik bir şekilde yürütülmesini sağlamak amacıyla sayısal bir özetle yapılandırılmıştır.

2.3. Dahil Etme Kriterleri

Çalışmada kullanılan dahil etme kriterleri aşağıda sunulmuştur.

1. Türkiye’de yapılmış olması
2. Örneklemi çocuklar veya eğitimciler olması

3. Çevre veya atık temasını içermesi
4. Tam metin olarak erişilebilir olması

2.4. Dışlama Kriterleri

Çalışmada kullanılan dışlama kriterleri aşağıda sunulmuştur.

1. Yetişkin örnekleme olan çalışmalar
2. 2017 öncesi yayınlar
3. Konu dışı çalışmalar

2.5. İstatistik Analiz

Çalışmaya dahil edilen yayınlar tematik analiz yöntemi ile değerlendirilmiştir. Tema belirleme sürecinde, çalışmaların araştırma amaçları, ele aldıkları temel konular ve bulguları dikkate alınmıştır. Bu doğrultuda elde edilen veriler üç ana tema altında sınıflandırılmıştır:

1. Dönüştürülebilir atıkların çocuk sağlığı üzerindeki etkileri
2. Çocuklarda çevresel farkındalık gelişimi
3. Eğitim programları ve sıfır atık uygulamalarının etkileri

3. Bulgular

3.1. Dönüştürülebilir Atıkların Çocuk Sağlığına Etkileri

Literatür, atık yönetiminin çocuk sağlığı üzerindeki etkilerini özellikle solunum hastalıkları, alerjik reaksiyonlar, dermatolojik problemler ve nörolojik etkiler bağlamında ele almaktadır (Bayraktar ve Fırat, 2020).

3.1.1. Solunum sistemi etkileri

Plastik ve kâğıt atıklarının yakılmasıyla açığa çıkan PM2.5 partikülleri astım, hışıltı ve kronik öksürüğü artırmaktadır (Bayraktar ve Fırat, 2020).

Atıkların açık alanda depolanması çocuklarda:

- Nefes darlığı,
- Tekrarlayan bronşit,
- Sinüzit gibi sorunlara yol açmaktadır (Bayraktar ve Fırat, 2020).

3.1.2. Alerjik ve dermatolojik etkiler

Çöp ayrıştırmanın yapılmadığı bölgelerde çocuklarda:

- Egzama,
- Kontakt dermatit,
- Göz tahrişi daha yaygın görülmektedir (Ural ve Keleş, 2018).

3.1.3. Elektronik Atıkların Etkisi

Elektronik atıkların uygunsuz bertarafı ile ortaya çıkan kurşun, cıva ve kadmiyum çocuklarda:

- Dikkat eksikliği,
- Motor koordinasyon bozukluğu,
- Öğrenme güçlüğü ile ilişkilendirilmiştir (WHO, 2022).

3.2. Çocuklarda Çevresel Farkındalık Gelişimi

3.2.1. Aile etkisi

Aile içinde geri dönüşüm uygulamaları yapan evlerde yetişen çocukların farkındalığı daha yüksektir (Tümer, 2017).

3.2.2. Eğitimsel etkiler

Okullarda uygulanan çevre eğitimi, geri dönüşüm etkinlikleri ve çevre kulüpleri öğrencilerin bilgi ve tutumlarını güçlendirmektedir (Tümer, 2017).

3.2.3. Sosyoekonomik faktörler

Sosyoekonomik düzeyi yüksek bölgelerde çevre farkındalığı daha yüksek olmakla birlikte, okul temelli uygulamalar bu farkı azaltabilmektedir (Taşan, 2024).

3.3. Eğitim Programları, Sıfır Atık Yaklaşımı ve Uygulamalı Etkinlikler

3.3.1. Uygulamalı öğrenme

Atık materyallerle yeni ürünlerin tasarlanması çocukların çevre sorumluluğunu somutlaştırmaktadır (Kazu ve Yapıcı Ödemiş, 2023).

3.3.2. Proje tabanlı etkinlikler

Geri dönüşüm panoları, sınıf içi sıfır atık köşeleri ve okul projeleri farkındalığı artırmaktadır (Taşan, 2024).

3.3.3. Sıfır Atık Projesi'nin Katkıları

Sıfır Atık Projesi çocuklarda:

- Davranış değişikliği,
- Atık ayrıştırma becerisi,
- Sürdürülebilir yaşam alışkanlıkları geliştirmektedir (Taşan, 2024).

4. Tartışma

Bu çalışma, dönüştürülebilir atıkların çocuk sağlığı üzerindeki etkilerini geniş literatür kapsamında değerlendirmiştir (Bayraktar ve Fırat, 2020). Bulgular çocukların çevresel kirlenmelere karşı son derece duyarlı olduğunu göstermektedir (WHO, 2022). Uluslararası literatürle karşılaştırıldığında Türkiye'de e-atıkların etkilerini inceleyen çalışmaların sınırlı olduğu görülmüştür (Taşan, 2024). Sürdürülebilir çevre davranışlarının yerleşmesi için okul ve aile iş birliği kritik öneme sahiptir (Tümer, 2017). Uygulamalı eğitimler ve proje tabanlı öğrenme çocuklarda davranış değişikliğini hızlandırmaktadır (Kazu ve Yapıcı Ödemiş, 2023). Sıfır Atık Projesi ise ulusal ölçekte farkındalık yaratmış olsa da uygulamada kurumsal farklılıklar gözlenmektedir (Taşan, 2024). 2024 yılında Tamkoç ve arkadaşları, "Sıfır Atık Projesi ile öğrencilerde Oluşan Atık Yönetimi ve Geri Dönüşüm Farkının Değerlendirilmesi Sıfır Atık Projesi ile Öğrencilerin Atık Yönetimi ve Geri Dönüşüm Farkındalığının Değerlendirilmesi" isimli çalışmalarında, Çevre, Şehircilik ve İklim Değişikliği Bakanlığı tarafından yürütülen 'Sıfır Atık Projesi'nin uygulanması sonucunda ilkokul öğrencilerinin atık yönetimi ve geri dönüşüm konusundaki farkındalıklarını değerlendirmeyi amaçlamışlardır.

5. Sonuç

Dönüştürülebilir atıklar, çevresel sürdürülebilirlik açısından önemli fırsatlar sunmakla birlikte, özellikle çocuk sağlığı açısından dikkate alınması gereken çeşitli riskleri de beraberinde getirmektedir. Çocukların gelişimsel özellikleri, bağımsızlık sistemlerinin henüz tam olarak olgunlaşmamış olması, çevresel toksinlere karşı

daha duyarlı olmaları ve ev içi/okul ortamlarında atıklarla daha sık temas etmeleri, bu riskleri yetişkinlere kıyasla belirgin şekilde artırmaktadır. Plastik, metal, elektronik atıklar, organik atıklar ve kimyasal içerikli materyaller; solunum yolu hastalıkları, dermatolojik sorunlar, gastrointestinal enfeksiyonlar, ağır metal maruziyeti, gelişimsel gecikmeler ve nörotoksik etkiler gibi çok boyutlu sağlık sonuçlarına yol açabilmektedir. Bu araştırma, dönüştürülebilir atıkların çocuk sağlığına etkilerini değerlendirdiğinde, risklerin yalnızca yanlış atık yönetiminden değil; ebeveyn farkındalığının yetersizliği, okullarda geri dönüşüm uygulamalarının standartlaştırılmaması, yerel yönetimlerin eksik denetimleri ve çevresel maruziyetin sosyoekonomik eşitsizliklerle ilişkili olmasından da kaynaklandığını göstermektedir. Özellikle elektronik atıkların içerdiği ağır metaller (kurşun, kadmiyum, cıva) çocuklarda bilişsel, davranışsal ve motor gelişimi olumsuz etkileyebilmekte; plastik türevlerinin parçalanmasıyla açığa çıkan mikroplastikler ise uzun vadeli sağlık etkileri henüz tam anlaşılmamış olmasına rağmen potansiyel bir tehdit oluşturmaktadır. Tüm bu bulgular, dönüştürülebilir atık yönetiminin sadece çevresel bir süreç değil, aynı zamanda çocuk sağlığını doğrudan etkileyen bir halk sağlığı konusu olduğunu ortaya koymaktadır. Bu nedenle, çocukların atık kaynaklı sağlık risklerinden korunması için bütüncül yaklaşımlar gereklidir. Ebeveynlere ve eğitimcilere yönelik farkındalık programlarının artırılması, çocuklara uygun güvenli geri dönüşüm uygulamalarının oluşturulması, atık toplama ve ayrıştırma noktalarının düzenli denetlenmesi ve yerel yönetimlerin çocuk sağlığını merkeze alan politika ve uygulamalar geliştirmesi kritik öneme sahiptir. Ayrıca mikroplastikler, elektronik atık toksisitesi ve düşük düzeyde maruziyetin uzun vadeli etkileri gibi konularda daha fazla bilimsel araştırmaya ihtiyaç vardır.

Sonuç olarak, dönüştürülebilir atık yönetimi süreçlerinde çocukların korunması ve sağlıklı gelişimlerinin desteklenmesi, çok sektörlü iş birliğini gerektiren bir önceliktir. Bu çerçevede yapılacak bilimsel araştırmalar, politika geliştirme çalışmaları ve toplum eğitimleri, hem çevresel sürdürülebilirliği güçlendirecek hem de çocukların sağlıklı bir çevrede büyümesine katkı sağlayacaktır. Çalışma kapsamında yapılan öneriler aşağıda sunulmuştur.

Eğitimcilere:

- Uygulama temelli geri dönüşüm etkinlikleri artırılmalı (Tümer, 2017).
- Sıfır atık eğitimleri tüm derslere entegre edilmeli (Taşan, 2024).

Ailelere:

- Evde atık ayrıştırma yapılmalı (Tümer, 2017).
- Çocuklarla çevre etkinlikleri düzenlenmeli (Kazu ve Yapıcı Ödemiş, 2023).

Politika Yapıcılara:

- E-atık yönetimi güçlendirilmeli (Taşan, 2024). Okullara daha fazla kaynak aktarılmalı (UNEP, 2023).

Katkı Oranı Beyanı

Yazarların katkı yüzdeleri aşağıda verilmiştir. Yazarlar makaleyi incelemiş ve onaylamıştır.

%	M.A.	E.G.
K	50	50
T	50	50
Y	50	50
VTI	50	50
VAY	50	50
KT	50	50
YZ	50	50
GR	50	50
PM	50	50

K= kavram, T= tasarım, Y= yönetim, VTI= veri toplama ve/veya işleme, VAY= veri analizi ve/veya yorumlama, KT= kaynak tarama, YZ= Yazım, GR= gönderim ve revizyon, PY= proje yönetimi.

Çatışma Beyanı

Yazarlar bu çalışmada hiçbir çıkar ilişkisi olmadığını beyan etmektedirler.

Etik Onay Beyanı

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RIVER WATER QUALITY AND TRACE CONTAMINANTS IN GLOBAL RESEARCH WITH SCIENTOMETRIC ANALYSIS

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Abstract: Rivers play a vital role in sustaining ecological systems, human societies, and regional economies, yet their water quality is increasingly threatened by trace contaminants and intensifying anthropogenic pressures. Despite the rapid growth of scientific output in this domain, global knowledge remains fragmented across regions, pollutants, and methodological approaches. This study provides a comprehensive scientometric assessment of research on river water quality and trace contaminants using 2,428 publications retrieved from the Web of Science Core Collection (1976–2025). A structured search strategy and exclusion criteria were applied to isolate records focusing specifically on trace elements, heavy metals, micropollutants, and related hydrochemical processes in riverine environments. Scientometric analyses—conducted using the bibliometrix package and Biblioshiny—include performance metrics, collaboration mapping, co-citation structures, bibliographic coupling, and co-word networks. The results reveal an accelerating annual growth rate (11.36%), dominated by contributions from China, India, and the USA, alongside a rising but uneven pattern of international collaboration. Keyword co-occurrence and clustering analyses identify three major thematic domains: (i) heavy-metal contamination and pollution assessment; (ii) basin-wide hydrochemical processes and source apportionment; and (iii) toxicological evaluations of individual trace metals. Emerging research fronts highlight increasing integration of advanced statistical techniques, GIS-based modelling, and ecological risk frameworks. Overall, this study elucidates the intellectual structure, knowledge gaps, and evolving research directions within global river contamination studies. The findings provide an evidence-based foundation for strengthening monitoring strategies, guiding policy development, and advancing interdisciplinary approaches essential for sustainable river basin management.

Keywords: River water quality, Hydrochemistry, Trace contaminants, Heavy metals, Scientometric analysis

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1. Introduction

Water resources form the foundation of ecological integrity, social well-being, and economic sustainability (Pant et al., 2025). Among these resources, surface waters—particularly rivers—play a pivotal role in regional water management by providing drinking-water supplies, hydropower generation, irrigation for agriculture, industrial water demands, ecological habitat maintenance, and essential urban services (Kannel et al., 2007; Jiang et al., 2012; Al-Badai et al., 2013; Tirink et al., 2025). However, accelerating global water demand, coupled with the intensifying impacts of climate change, has placed unprecedented pressure on river water quality (Pant et al., 2025). The chemical composition of river systems is shaped by an interplay of natural factors—such as geology, flow regime, and hydrodynamics—and a wide range of anthropogenic

inputs, including industrial and domestic effluents, agricultural nutrient enrichment, pesticide application, mining activities, and rapid urban expansion (Hamid et al., 2019; Akhtar et al., 2021; Tirink and Özkoç, 2021; Anh et al., 2023; Böke Özkoç et al., 2025).

In recent years, increasing attention has focused on emerging micropollutants—including pharmaceuticals, heavy metals, and microplastics—which may exert toxic effects even at trace concentrations and are often insufficiently removed by conventional treatment processes (Morin-Crini et al., 2022; Wilkinson et al., 2017; Folorunsho et al., 2025; De Heredia et al., 2024; Arıman et al., 2026). Seasonal hydrological fluctuations further modulate the distribution, persistence, and transport of these contaminants in riverine environments (Anh et al., 2023; De Heredia et al., 2024; Pant et al., 2023). In addition to seasonal hydrological



fluctuations, several other factors influence the behavior and environmental impact of trace contaminants in river systems, including changes in flow regime, sediment-water interactions, physico-chemical parameters (e.g., temperature, pH, dissolved oxygen), land-use pressures, industrial and agricultural discharges, and extreme climatic events (Tirink et al., 2025; Arıman et al., 2026). Evidence from multiple continents demonstrates that rivers are highly sensitive to both anthropogenic disturbances and climate-driven alterations, which jointly influence their chemical, hydrological, and ecological functioning (Shrivastava et al., 2025; Whitehead et al., 2009; Liu et al., 2024; Abushandi, 2025; Pant et al., 2025).

Despite their critical importance, significant knowledge gaps persist—particularly in low- and middle-income regions—where monitoring infrastructures remain insufficient and data on both traditional and emerging contaminants are fragmented or unavailable (Morin-Crini et al., 2022; De Heredia et al., 2024; Kandel et al., 2024). Existing studies are predominantly basin- or site-specific, resulting in limited global syntheses and a scarcity of long-term, multi-parameter datasets that would allow robust comparative assessments (Morin-Crini et al., 2022; Wilkinson et al., 2017; Sun and Song, 2025). Furthermore, the disconnect between scientific evidence and policy implementation continues to hinder the development of effective river basin management frameworks (Akhtar et al., 2021; Ren et al., 2025). Such constraints underscore the need for more comprehensive, longitudinal, and integrative research efforts, as well as standardized monitoring protocols that can support evidence-based water governance at global and regional scales (Kandel et al., 2024; Tirink et al., 2025).

Although research output on water quality has expanded rapidly, scholarly contributions remain unevenly distributed across geographical regions, contaminant categories, and methodological approaches. This fragmentation complicates cross-regional comparisons, obscures global patterns, and limits the development of universally applicable management strategies (Kandel et al., 2024). Moreover, despite the proliferation of studies, systematic evaluations capable of mapping the intellectual structure of the field—its conceptual evolution, leading contributors, and emerging research fronts—are still insufficient.

Scientometric analysis has therefore emerged as a powerful tool to address these shortcomings. By quantitatively examining publication trends, citation structures, collaborative authorship networks, and thematic clusters, scientometric methods reveal the cognitive architecture of a research domain and elucidate its developmental trajectories (Pritchard, 1969; Donthu et al., 2021). Such analyses also illuminate methodological shifts, including the increasing integration of advanced statistical techniques, GIS-based modeling, and machine-learning approaches into river

water quality assessment. Synthesizing dispersed studies through scientometric techniques enables researchers to identify evolution patterns in scientific inquiry, determine which contaminants and processes dominate academic attention, and pinpoint persisting knowledge gaps that require targeted investigation.

In this context, the present study conducts a comprehensive scientometric assessment of global research on river water quality and trace contaminants using the Web of Science (WoS) Core Collection. Specifically, the study aims to: (i) map dominant, emerging, and declining thematic structures within the literature; (ii) identify spatial and conceptual knowledge gaps requiring further research; and (iii) examine global scientific collaboration by analyzing co-authorship, institutional linkages, and country-level research networks. By integrating these components, this work provides an evidence-based overview of the field's intellectual evolution and supports the development of more effective monitoring frameworks and sustainable management strategies for river systems worldwide.

2. Material and Methods

2.1. Data Source and Search Strategy

The scientific dataset used in this study was obtained from the Web of Science (WoS) Core Collection, one of the most widely recognized and rigorously curated multidisciplinary citation databases. WoS is commonly used in scientometric studies due to its transparent indexing criteria, comprehensive metadata, and robust citation structure (Donthu et al., 2021). WoS was selected because it provides robust citation information and comprehensive metadata on publications across water sciences, environmental engineering, hydrology, and geochemistry.

All records were retrieved from WoS Core Collection on [30.11.2025], ensuring dataset reproducibility. The search included all WoS indices accessible through the Core Collection interface. Only research articles and review articles indexed in WoS Core Collection were included. Document types such as conference proceedings, book chapters, editorial materials, and meeting abstracts were excluded. Additionally, Early Access publications and records assigned to the publication year 2026 were filtered out to maintain consistency in the temporal distribution of the dataset. No language restrictions were applied initially; however, only English-language publications were retained for analysis to ensure standardized keyword interpretation.

To identify global research related to trace contaminants and river water quality, a Topic Search (TS) query was constructed using Boolean operators. The TS field retrieves terms appearing in the title, abstract, author keywords, and Keywords Plus. The final search query was:

```
TS=("water quality" OR "hydrochemistry" OR "hydrogeochemistry" OR "pollution assessment") AND
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TS=("trace elements" OR "trace metals" OR "heavy metals" OR "emerging contaminants" OR "micropollutants" OR "metal contamination" OR "metal pollution")

AND

TS=("river" OR "rivers" OR "stream" OR "streams" OR "river water" OR "lotic system" OR "fluvial system")

NOT

TS=("wastewater" OR "groundwater" OR "lake" OR "reservoir" OR "sewage" OR "estuary" OR "coastal")

2.2. Scientometric Analysis

In this study, a scientometric approach was employed to investigate how machine learning applications for live-weight estimation have evolved within the scientific landscape, with emphasis on publication dynamics, collaboration structures, and methodological trends. Scientometric analysis provides a systematic framework for evaluating the quantitative characteristics of scientific output in a specific domain, including publication volume, scientific impact, thematic structures, and patterns of scholarly cooperation (Pritchard, 1969; Donthu et al., 2021). By quantitatively examining the existing literature, it becomes possible to track the development of the field, assess research performance, identify dominant themes, and detect emerging directions for future inquiry.

Scientometric analysis and network visualization were conducted using the *bibliometrix* package in R (version 2025.09.2) and the Biblioshiny interface, which provides a web-based implementation of the *bibliometrix* framework (Aria and Cuccurullo, 2017; R Core Team, 2022).

The methodological workflow followed established scientometric mapping principles and consisted of:

2.2.1. Performance analysis

Performance analysis, including publication trends, productive countries, influential journals, and citation patterns.

2.2.1. Science mapping

Science mapping, incorporating:

- co-authorship networks (collaboration structures),
- co-citation analysis (intellectual foundations),
- bibliographic coupling (current thematic convergence),
- co-word analysis (emerging research frontiers via term co-occurrence).

Cluster detection relied on association normalization and Louvain modularity optimization, a robust and widely recommended algorithm for identifying thematic communities in scientometric networks (Donthu et al., 2021). Network nodes and edge weights were interpreted using centrality measures to highlight leading contributors, evolving research topics, and scientifically influential countries.

3. Results

Figure 1 provides an overview of the fundamental scientometric characteristics of the dataset obtained from the Web of Science Core Collection. This summary offers a concise snapshot of the scope, productivity, and collaborative nature of global research on trace contaminants and river water quality. The figure serves as the foundation for interpreting publication trends, authorship patterns, and thematic diversity within the field.



Figure 1. Main scientometric indicators of the dataset retrieved from the Web of Science Core Collection (1976–2025).

Figure 1 shows that the dataset includes 2,428 peer-reviewed documents published between 1976 and 2025, representing nearly five decades of scientific development. These publications are distributed across 633 scholarly sources, demonstrating the multidisciplinary nature of the field. The annual growth rate of 11.36% highlights a rapidly expanding research landscape, driven by growing global concern over riverine pollution and emerging contaminants.

A total of 9,862 authors contributed to the dataset, with an average of 4.95 co-authors per publication, indicating

substantial collaboration. International co-authorship accounts for 23.52% of all outputs, reflecting the global importance of river water quality issues and the increasing internationalization of environmental research.

The dataset contains 5,715 author keywords, evidencing significant thematic heterogeneity. With an average document age of 8.77 years, the field can be considered relatively young yet influential, as shown by a mean citation rate of 27.73 citations per article. Collectively, these metrics reveal an active, fast-growing, and

internationally collaborative research domain focused on understanding and mitigating trace contaminant dynamics in river systems.

Figure 2 illustrates the temporal evolution of scientific output related to river water quality and trace contaminants. Examining annual publication trends provides insight into how research interest, funding priorities, and global environmental concerns have shifted over time. The trend displayed in Figure 2 shows a pronounced and sustained increase in scientific

production from 1976 to 2025. For nearly two decades after 1976, annual publication numbers remained relatively low, reflecting the early developmental stage of research in hydrochemistry and pollutant monitoring. Beginning in the mid-1990s, however, the number of publications started to rise steadily, coinciding with advancements in analytical chemistry, environmental regulation frameworks, and increasing attention to riverine pollution.

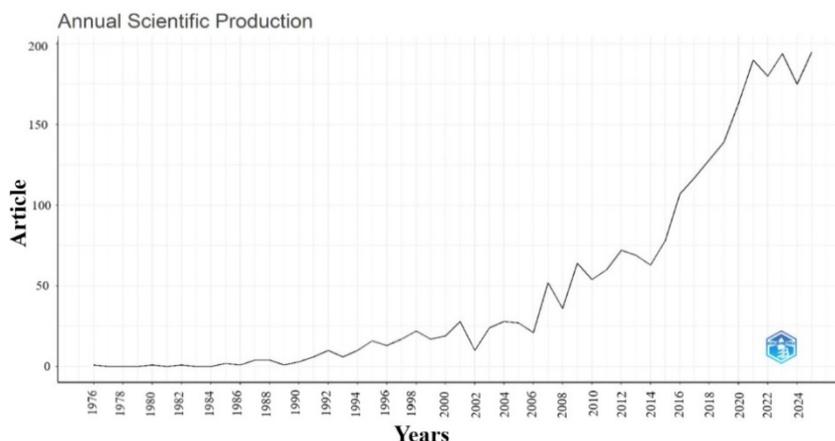


Figure 2. Annual scientific production (1976–2025) related to river water quality and trace contaminants.

A sharper upward trajectory becomes visible after 2005, followed by accelerated growth after 2015. This surge aligns with heightened global awareness of emerging contaminants, the proliferation of high-resolution monitoring technologies, and increased scientific emphasis on river systems as critical indicators of environmental change. The most substantial growth occurred between 2018 and 2024, when annual publication counts exceeded 150 articles per year, demonstrating intensified research activity across multiple disciplines including hydrology, environmental toxicology, and geochemistry.

Overall, the observed exponential growth pattern reflects a rapidly expanding research domain and underscores the growing urgency to address contamination risks, climate-driven hydrological changes, and water-resource sustainability challenges in river basins worldwide.

Figure 3 visualizes the relational structure among the most productive countries, leading authors, and frequently occurring author keywords in the field. This three-dimensional Sankey diagram provides an integrated view of how geographical research activity connects to influential contributors and thematic focuses. The diagram reveals that China, India, and the United States dominate publication output, forming the strongest nodes within the global research network. These countries exhibit extensive linkages to multiple authors and research themes, reflecting their large scientific communities and long-standing engagement with riverine pollution and trace element studies. Emerging contributors such as Türkiye, South Africa,

Pakistan, Germany, and the United Kingdom also display noticeable connectivity, demonstrating increasing regional involvement in contamination assessment and hydrogeochemical research.

At the author level, individuals such as Clements W.H., Li J., Kumar V., Iwasaki Y., Tokatlı C., Neal C., Baborowski M., and Ustaoglu F. appear as prominent nodes with strong thematic linkages. Their research primarily spans toxicity assessment, sediment contamination, trace-element dynamics, and hydrochemical evaluation—topics that align with global environmental monitoring priorities.

On the thematic side, frequently occurring keywords such as “heavy-metals,” “contamination,” “sediments,” “river,” “pollution,” “water-quality,” “trace-elements,” and “surface-water” indicate that research in this domain is heavily oriented toward understanding contaminant sources, sediment–water interactions, and ecological risks in river systems. The structural alignment between authors and keywords suggests clear thematic clustering around pollution assessment, toxicity, accumulation processes, and basin-scale hydrochemical studies.

Overall, Figure 3 illustrates a well-defined global research structure in which geographically diverse contributors converge around shared scientific issues. The strong overlap between leading countries, influential authors, and dominant environmental keywords highlights the maturation and thematic coherence of research on trace contaminants in riverine environments.

Figure 4 visualizes the relative frequency and thematic distribution of author keywords using a treemap layout.

Secondary but substantial clusters include keywords related to pollution (339.3%), risk (255.3%), surface water (222.2%), basin-scale studies (200.2%), sediments (186.2%), and trace elements (167.2%). These terms indicate a strong emphasis on contaminant transport, sediment–water interactions, basin hydrodynamics, and environmental risk assessment.

A diverse range of emerging and context-specific keywords also appears, such as “health,” “environmental,” “distribution,” “evaluation,” “monitoring,” “soil,” “fish,” “mining,” “urban,” “ecological,” “aquatic,” “multivariate,” and “toxic.” Their presence highlights the interdisciplinary expansion of the field toward ecological risk modeling, human-health implications, land-use effects, and the adoption of advanced analytical and statistical approaches.

Geographical identifiers like “China,” “India,” and “South” also appear among the frequent keywords, reinforcing

earlier findings that specific regions—particularly Asia—play a major role in global research production on riverine contamination.

Overall, the treemap demonstrates that while the field is strongly anchored in pollution assessment, metal contamination, and river water quality, it is simultaneously diversifying toward ecological, methodological, and region-specific research fronts. This thematic distribution underscores both the maturity and the expanding multidimensionality of research on trace contaminants in river systems.

Table 1 presents the scientometric performance indicators of the top contributing authors in the domain of river water quality and trace contaminants. Evaluating author-level metrics such as the h-index, g-index, m-index, total citations, and publication productivity provides insight into individual scientific influence and long-term contribution dynamics.

Table 1. Scientometric performance indicators of the most influential authors in the field of river water quality and trace contaminants, including h-index, g-index, m-index, total citations

Author	h_index	g_index	m_index	TC	NP	PY_start
CLEMENTS WH	15	21	0.441	1,140	21	1992
BABOROWSKI M	9	9	0.429	225	9	2005
NEAL C	9	10	0.31	498	10	1997
TOKATLI C	9	12	0.9	480	12	2016
USTAOGLU F	9	9	1.286	1,126	9	2019
KUMAR V	8	14	0.8	759	14	2016
SILLANPÄÄ M	8	8	0.444	1,721	8	2008
AVENANT-OLDEWAGE A	7	10	0.467	140	10	2011
ISLAM MS	7	7	1.167	530	7	2020
IWASAKI Y	7	11	0.412	201	11	2009

h-index: measures combined productivity and citation impact. *g-index*: emphasizes highly cited publications to reflect broader scholarly influence. *m-index*: h-index normalized by academic age for cross-career comparison. *TC*: total citations received by the author’s publications. *NP*: number of publications included in the dataset. *PY_start*: year of the author’s first publication recorded in this analysis.

The results show that Clements W.H. is the most influential author, with the highest h-index (15) and g-index (21), supported by 1,140 citations across 21 publications since 1992. His sustained academic output and long citation history reflect foundational contributions to toxicity assessment and riverine pollution research. Among mid-career contributors, Tokatlı C., Kumar V., and Iwasaki Y. exhibit strong citation performance relative to their publication counts. In particular, Tokatlı C. (h = 9; TC = 480) and Kumar V. (h = 8; TC = 759) have rapidly accumulated citations since entering the field in 2016, indicating rising influence and expanding scholarly visibility.

High m-index values, which normalize author impact by academic age, highlight rapidly emerging researchers. Ustaoglu F. displays the highest m-index (1.286), followed by Islam M.S. (1.167) and Tokatlı C. (0.900). These elevated m-indices suggest accelerated citation growth and demonstrate that these authors have become highly influential within a relatively short period of academic activity. Sillanpää M. stands out with the highest total citation count (1721) among authors with

moderate publication numbers (NP = 8), reflecting substantial impact per article. Academic contributors such as Baborowski M., Avenant-Oldewage A., and Neal C. also maintain steady influence through consistent productivity and notable citation performance. Overall, the author-level indicators reveal a diverse community of established researchers, rapidly emerging scholars, and region-specific contributors. The combination of long-term academic impact and rapidly growing new research profiles suggests that the field is both mature and expanding, driven by rising concerns over contamination processes, ecological risks, and water-quality deterioration in global river systems.

Figure 5 illustrates the geographic distribution of scientific output based on corresponding authors’ affiliations. Analyzing these patterns provides insight into which countries lead research efforts in river water quality and trace contaminants, as well as the extent to which international collaboration contributes to knowledge production.

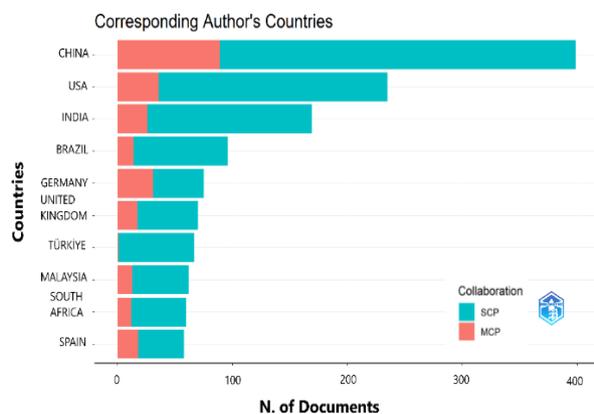


Figure 5. Corresponding authors’ countries and their contribution to the global scientific output related to river water quality and trace contaminants. (Note. SCP refers to publications authored within a single country, whereas MCP designates articles produced through international collaboration. Article frequency (%) represents each country’s share of total publications in the dataset.)

The results show that China is the dominant contributor, accounting for nearly 50% of all publications (36075 articles), with most classified as Single Country Publications (SCP) (30344). However, China’s MCP share remains relatively modest (15.9%), suggesting a high volume of domestic research activity with comparatively limited international collaboration.

India and Korea occupy the second and third positions, representing 12% and 6.6% of global output, respectively. Both countries show a balanced mix of SCP and MCP contributions, with India exhibiting a 23.4% MCP rate and Korea 27.2%, indicating a moderately collaborative research environment.

The United States, although contributing fewer total articles than China and India in this dataset (3.5% of publications), demonstrates a significantly higher commitment to international collaboration, with 33.4% of its research produced via MCPs. Similarly, Malaysia, Spain, and Egypt show MCP proportions exceeding 30%, highlighting their substantial involvement in cross-border scientific partnerships.

Notably, Australia stands out with the highest MCP percentage (64.2%), reflecting a highly collaborative research system where the majority of publications are produced with international co-authors despite a relatively modest article count. Countries such as Brazil and Iran exhibit predominantly domestic research structures, evidenced by SCP rates exceeding 75%.

Overall, the distribution underscores two parallel trends: (1) High-output countries like China and India primarily drive the global publication volume through domestic networks, while

(2) Medium-output but globally integrated countries such as Australia, Malaysia, Spain, and Egypt play a crucial role in knowledge exchange by contributing disproportionately to international collaboration.

These findings highlight a geographically uneven yet increasingly interconnected scientific landscape, where both research capacity and collaboration culture shape global knowledge production in riverine contamination studies. Figure 6 depicts the co-occurrence network of author keywords, revealing how thematic concepts cluster together within the scientific landscape. Mapping these relationships helps identify dominant research domains, emerging directions, and the conceptual structure underlying studies on river water quality and trace contaminants.

The network structure is organized into three major clusters, each representing a distinct thematic domain. The red cluster, which is the most densely connected, centers on keywords such as “heavy-metals,” “contamination,” “pollution,” “river,” “sediments,” and “water-quality.” These terms indicate the field’s primary research focus: evaluating heavy-metal pollution in riverine environments, understanding contamination pathways, and assessing ecological and human-health risks. Strong interlinkages within this cluster highlight an extensive body of work dedicated to metal behavior, bioaccumulation, exposure pathways, and sediment-water interactions.

The green cluster reflects a second major thematic dimension associated with hydrological, geochemical, and basin-scale assessments. Keywords such as “quality,” “basin,” “impacts,” “land-use,” “geochemistry,” “source apportionment,” and “surface-water” illustrate studies focused on watershed processes, pollution sources, spatial distribution patterns, and integrated river-basin management. This cluster represents an analytical and systems-level perspective, linking contaminant dynamics with broader hydrological and environmental drivers.

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The blue cluster, although smaller, represents a specialized domain centered on individual trace metals and toxicity effects. Terms such as “lead,” “cadmium,” “zinc,” “copper,” and “toxicity” emphasize contaminant-specific toxicological studies, laboratory exposure experiments, and risk evaluation approaches. The separation of this cluster from the others suggests focused subfields dealing with mechanistic and metal-specific toxic responses.

Overall, the network reveals a highly interconnected thematic structure, indicating that research on riverine trace contaminants consistently integrates pollution assessment, chemical behavior, environmental processes, and toxicity outcomes. The concentration of connections

around heavy metals demonstrates their enduring prominence as a central environmental concern, while emerging keywords associated with basin-scale processes and geochemical modeling highlight a shift toward more integrative and interdisciplinary approaches.

Figure 7 provides a visual summary of the most frequently occurring author keywords using a word cloud representation. This visualization highlights the dominant conceptual areas in the literature by scaling each term according to its frequency of appearance.

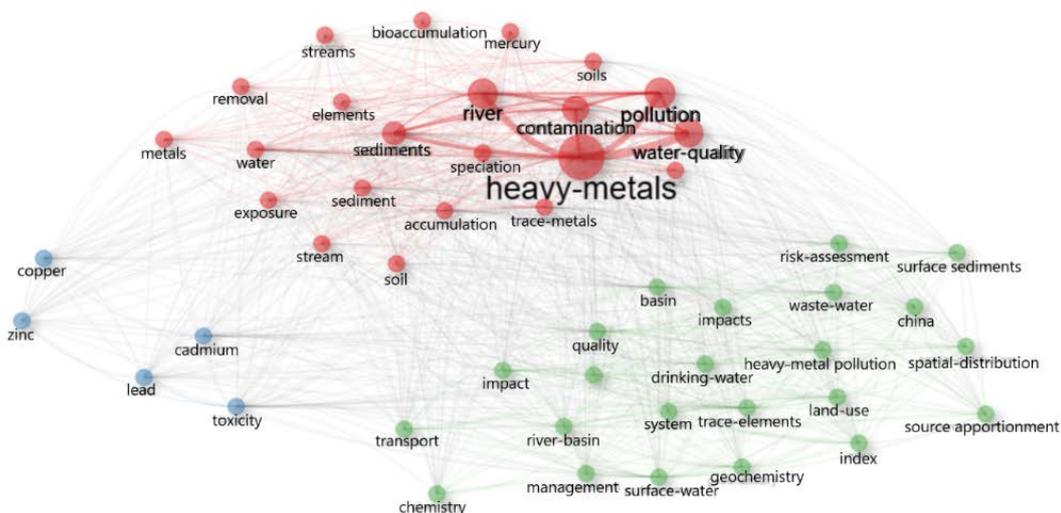


Figure 6. Keyword co-occurrence network illustrating thematic clusters in the literature on river water quality and trace contaminants



Figure 7. Word cloud showing the most frequent author keywords in the dataset.

The most prominent keywords—including “water quality,” “contamination,” “river,” “pollution,” “sediments,” and “trace-elements/trace-metals”—indicate that research on riverine environments is strongly concentrated on evaluating pollutant loads, assessing contamination status, and monitoring chemical and ecological conditions. The size of these terms suggests their centrality to the field’s conceptual

framework, consistent with earlier co-occurrence network findings.

Other frequently appearing keywords such as “surface-water,” “basin,” “land-use,” “waste-water,” “spatial-distribution,” and “source apportionment” demonstrate an expanding focus on watershed-scale processes, pollution sources, and spatial modeling approaches. These terms also reflect a methodological shift toward

integrated hydrological-geochemical assessments and basin-level risk analysis.

The presence of contaminant-specific terms—including “cadmium,” “lead,” “zinc,” “copper,” “mercury,” and “bioaccumulation”—indicates ongoing attention to metal toxicity, exposure pathways, and bioaccumulation mechanisms within aquatic systems. Meanwhile, keywords such as “impacts,” “toxicity,” “evaluation,” and “drinking-water” underscore the relevance of environmental and human-health risk considerations. Overall, the word cloud reveals a lexicon dominated by pollution assessment and chemical contamination, complemented by emerging interests in watershed processes, spatial analyses, and ecosystem-level impacts. This thematic diversity reflects the field’s evolution from pollutant characterization toward more integrative, multidisciplinary approaches in river water quality research.

4. Conclusion

This study provides a comprehensive scientometric assessment of global research on river water quality and trace contaminants, revealing a rapidly expanding and increasingly interdisciplinary field. The analysis shows that heavy-metal pollution, hydrochemical processes, and ecological risk assessment remain the core scientific themes, while emerging studies incorporate advanced statistical techniques, geochemical modeling, and basin-scale environmental evaluations. Despite the growing volume of research, geographic and thematic gaps persist, particularly in underrepresented regions where monitoring efforts and long-term datasets are limited.

The findings highlight the need for more standardized assessment protocols, integrated analytical approaches, and stronger connections between scientific evidence and water-management policy. As the pressures of climate change and anthropogenic activities intensify, future research will benefit from broader spatial coverage, improved data quality, and collaborative frameworks that link hydrological, ecological, and geochemical perspectives. Overall, this study maps the intellectual structure of the field and provides a foundation for developing more effective strategies to protect and sustainably manage river ecosystems worldwide.

Author Contributions

The percentages of the authors’ contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	S.T.	K.K.	SA.
C	30	40	30
D	30	40	30
S	30	40	30
DCP	30	40	30
DAI	30	40	30
L	30	40	30
W	30	40	30
CR	30	40	30
SR	30	40	30
PM	30	40	30
FA	30	40	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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BIOPIRACY OF HEIRLOOM SEEDS: ECOLOGICAL RISKS AND THE BIOLOGICAL NECESSITY FOR CONSERVATION POLICIES

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Abstract: This study aims to examine the impacts of the recent increase in biopiracy and bio-smuggling activities on heirloom seeds and to evaluate the implications of these practices on ecological balance and food sovereignty. In particular, the illegal collection of plant genetic resources and their patenting followed by re-sale to their countries of origin have brought the concept of biopiracy to the forefront. Such practices pose significant threats to local agricultural systems, farmers' rights, and biological diversity. This research, which is based on an extensive review of the literature, emphasizes that the preservation of heirloom seeds is not only a cultural and agricultural necessity but also a critical component of sustaining ecological balance. The smuggling of heirloom seeds abroad and their subsequent genetic modification and commercial cultivation in different geographical regions not only undermines the biological heritage of the source countries but also disrupts ecological systems. When cultivated outside their native habitats, these plants may exhibit invasive species behavior or trigger ecological imbalances in new environments. Moreover, this process exacerbates the degradation of already fragile local ecosystems, especially in the context of climate change. This study highlights the urgent need for comprehensive national and international policies to protect heirloom seeds in biodiversity-rich countries such as Türkiye. Based on literature-derived data, the study presents a set of policy recommendations developed by the authors to combat biopiracy through legal, scientific, and social awareness frameworks. These recommendations offer strategic guidance for both nature conservation and sustainable agricultural policymaking.

Keywords: Biopiracy, Ecological balance, Heirloom seeds, Plant genetic resources, Sustainability

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1. Introduction

Biodiversity is an indispensable resource for the functioning of ecosystems, the maintenance of food security, and human well-being (FAO, 2019; IPBES, 2019). However, this richness is currently under severe threat due to habitat loss, climate change, intensive agricultural practices, and the impacts of globalization (CBD, 2020).

Among these threats, one of the most pressing issues in recent years has been 'biopiracy,' referring to the unauthorized or inequitable acquisition of genetic resources, particularly heirloom seeds (Louafi and Tobin, 2005; Robinson, 2010). Biopiracy not only undermines ecological balance but also violates the rights of traditional knowledge holders and local communities. Therefore, the protection of heirloom seeds has become a critical necessity for ensuring the sustainability of biodiversity and safeguarding biocultural heritage for future generations.

Biopiracy is defined as the illegal acquisition and commercialization of a country's biological resources,

particularly local plant genetic material. This phenomenon is not merely the theft of a species but also the usurpation of the rights of local communities that have preserved and developed these resources for centuries. In this context, biopiracy refers not only to the unlawful appropriation of biological materials but also to the exclusion of local communities' innovation and knowledge production processes through intellectual property regimes (Drahos and Frankel, 2012). The unlawful collection and export of heirloom seeds can lead to the irreversible loss of genetic heritage, while corporations often subject these resources to genetic modification and patenting, forcing the country of origin to repurchase its own resources at high costs. The consequences extend beyond economic losses, causing severe ecological disruptions; when seeds are removed from their natural habitats, they may either fail to adapt to new environments or, conversely, spread invasively, threatening native species and reducing biodiversity. Combined with the pressures of climate change, this process further weakens the resilience of already fragile



ecosystems (Gulyani and Singh, 2010; Güler, 2022; Güler 2025).

In countries rich in biodiversity, such as Türkiye, home to thousands of endemic plant species, biopiracy must be addressed not only as an environmental concern but also as a matter of national security. Addressing the impacts of biopiracy on heirloom seeds requires closing legal gaps, accelerating scientific inventory studies, and enhancing public awareness. Thus, the protection of heirloom seeds is not only about preserving cultural heritage but also about ensuring ecological stability, food sovereignty, and sustainable development for the future (Ribeiro and Ribeiro 2019; TAGEM 2021; Erat and Balık, 2022; Güler 2025).

As highlighted by Elliott (2011), biopiracy is a global issue rooted in historical exploitation and contemporary inequities, demanding international recognition and collective action involving governments, researchers, industry, farmers, and indigenous people. In the literature, heirloom seeds are generally referred to as "heirloom seeds" or "landrace varieties." Beviláqua et al. (2014) define them as follows: "Heirloom seeds are varieties produced by farmers, which may be of local origin or come from other regions/countries, but through long-term cultivation in a particular place, they undergo a process of specific adaptation to the environment." In Brazil and Portugal, they are described as "sementes crioulas," which are not only genetic material but also carriers of traditional knowledge, elements that enhance socio-bioagricultural diversity, resources that support the peasant way of life, and sources closely linked to agroecological and/or organic production.

In this context, the purpose of this study is to examine the impacts of the recent increase in biopiracy and bio-smuggling activities on heirloom seeds, to assess their consequences for ecological balance and food sovereignty, and to contribute to the development of solution-oriented policy recommendations based on legal, scientific, and social awareness frameworks. To achieve this purpose, the study employs a bibliometric analysis of the scientific literature on biopiracy, genetic resources, and heirloom seeds. This method enables the identification of research trends, thematic gaps, and dominant policy perspectives, thereby strengthening the analytical framework of the study and providing an evidence-based foundation for the proposed recommendations.

2. Materials and Methods

2.1. Data Collection

For the bibliometric analysis, only Web of Science data were used, as this database provides the most advanced and detailed coverage of peer-reviewed scientific literature. Bibliographic records were downloaded from the Web of Science Core Collection in BibTeX format, including full records and cited references, and used as the input dataset for the bibliometric analysis. The bibliometric analysis was conducted to systematically

identify research trends, thematic concentrations, and gaps in studies addressing biopiracy, genetic resources, and heirloom seeds, thereby supporting the overall objective of the study. This approach enables a structured evaluation of the scientific landscape and provides an empirical basis for interpreting the ecological and policy-related implications of biopiracy. In addition, publications obtained from Google Scholar, Scopus, and the YÖK Thesis Database were considered in the discussion section to contextualize the bibliometric findings and enrich the interpretation of the results.

2.2. Analysis

A search was conducted using the keywords "*biopiracy*", "*bio-piracy*", "*bio piracy*", "*heirloom seed*", "*landrace varieties*", "*traditional seeds*", "*local seeds*", "*genetic resources*", and "*plant genetic resources*" (Figure 1). The retrieved bibliographic data were analyzed in R Studio using the bibliometrix package (Tırnık, 2020; Abdullah, 2022), which is widely employed for bibliometric and scientometric analyses to examine publication trends, citation structures, keyword co-occurrence, and collaboration networks. Previous studies have demonstrated that R-based bibliometric analysis tools are increasingly used in biology and science education research and are effective in revealing publication trends and research dynamics (Abdullah, 2022). In recent years, R Studio has been widely adopted not only in ecological and agricultural sciences but also in fields such as educational sciences and microbiology for bibliometric and mapping analyses (Fidiastuti, 2025). This analytical framework follows established bibliometric approaches applied in recent studies, where R-based bibliometric tools have been effectively used to map scientific production and research dynamics across disciplines.

In line with this methodological approach, R Studio has become one of the most widely used statistical analysis tools and is frequently preferred by researchers conducting bibliometric studies in the field of biology. Bibliometric analysis is a method that examines scientific literature through quantitative indicators to reveal research trends, collaboration patterns, and thematic developments. In this way, the data in this study were evaluated objectively, systematically, and in a visually interpretable manner (Kurtuluş and Bilen, 2021).

2.3. Indicators

The dataset was examined in terms of publication year distribution, country contributions, author collaborations, citation frequencies, and thematic focus areas.

2.4. Visualization and Discussion

Findings were visualized through graphs, trend lines, and network maps to ensure clarity in the poster presentation. The results were further discussed in light of case reports, legal practices, and the relevant literature.

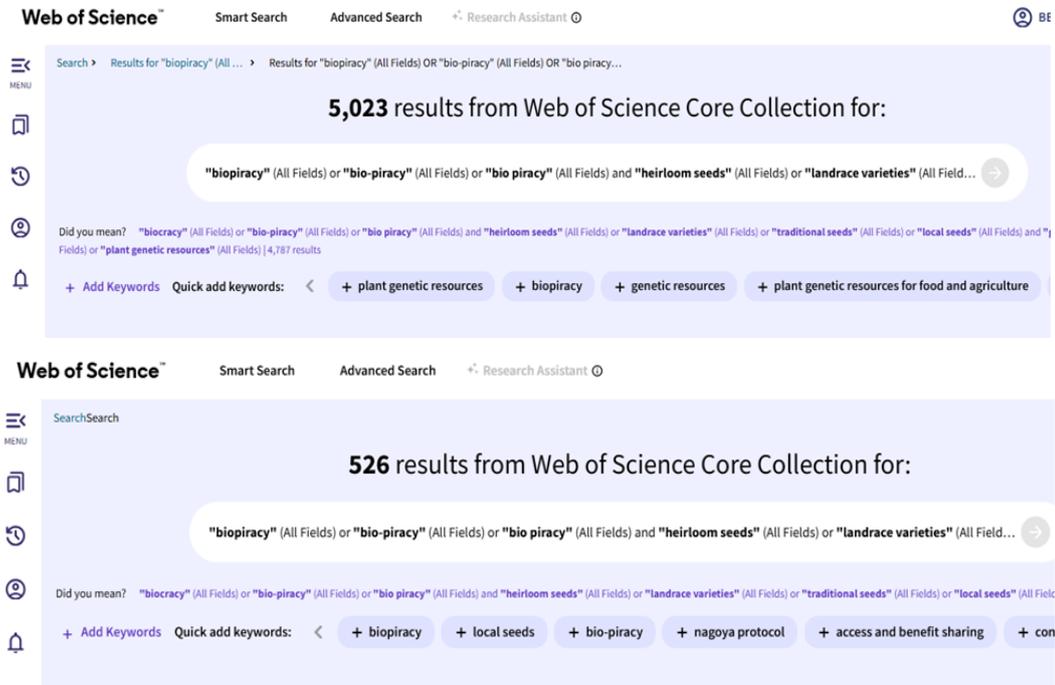


Figure 1. Web of Science search results.

3. Results and Discussion

Between 1980 and 2025, 5024 documents, 1196 sources, and 15,779 authors were identified. The annual average growth rate was 12.58 %, indicating increasing academic attention to the subject. Studies were predominantly multi-authored with an average of 4.84 authors per paper, while single-authored works were limited to 520. The rate of international co-authorship was 24.9 %. A total of 10,664 different keywords were used, reflecting the thematic diversity of the field. The average document age was 9.65 years, and the mean citation rate was 13.02 per paper. These results suggest that the topic of biopiracy and heirloom seeds is both current and of high impact potential. The findings further reveal that research on biopiracy and heirloom seeds has attracted increasing attention from scholars over the past four decades, with a rapid growth trend in recent years. The

prominence of collaborative studies underscores the interdisciplinary and international dimensions of the subject. Moreover, the wide variety of keywords indicates that the issue is addressed not only from ecological and agricultural perspectives but also from legal and socio-economic standpoints. (See Figures 2 and 3).

The analysis shows that Plant Genetic Resources–Characterization and Utilization and Genetic Resources and Crop Evolution are the leading journals in terms of both number of publications and citation impact. Sources such as Frontiers in Plant Science and Crop Science also play a significant role, indicating an interdisciplinary research structure. The cumulative trend reveals a rapid increase in contributions from these journals, especially after 2010, highlighting the growing scientific attention to biopiracy and plant genetic resources.

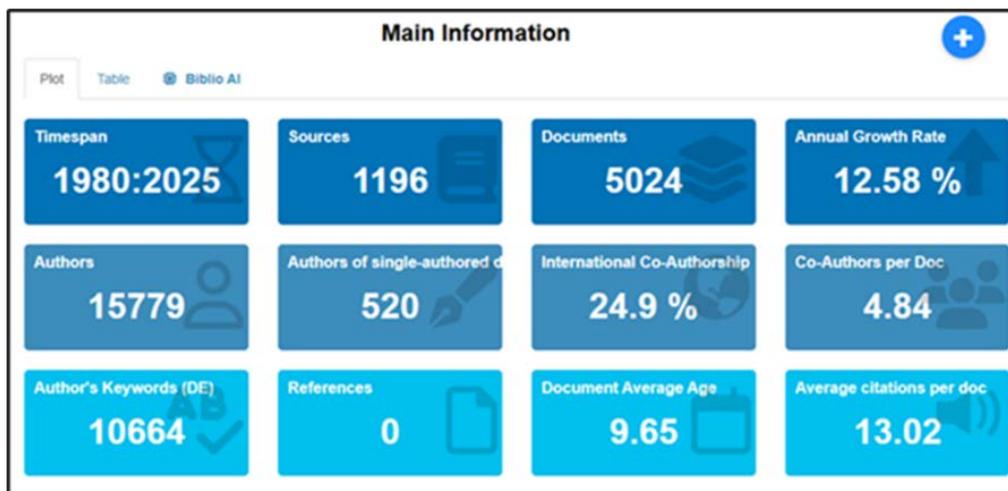


Figure 2. Main bibliometric indicators from Web of Science (1980–2025).

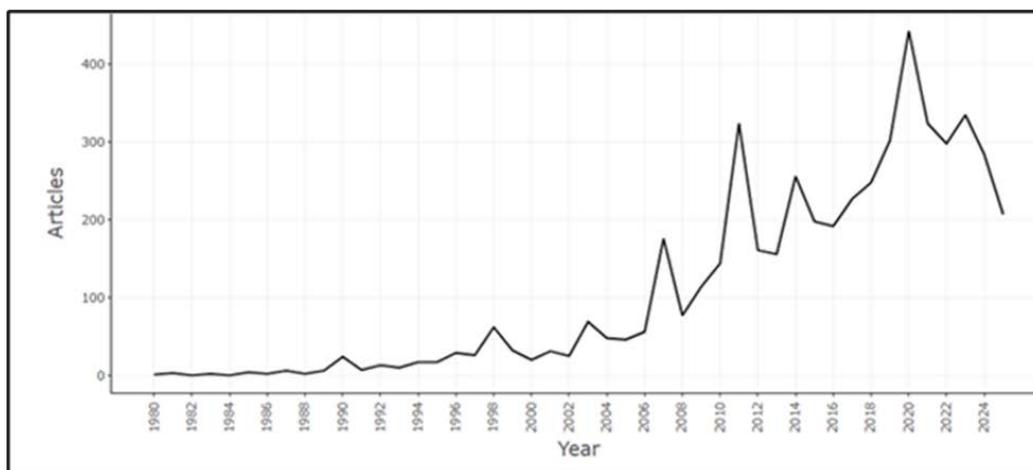


Figure 3. Annual number of publications on biopiracy and heirloom seeds in Web of Science (1980–2025).

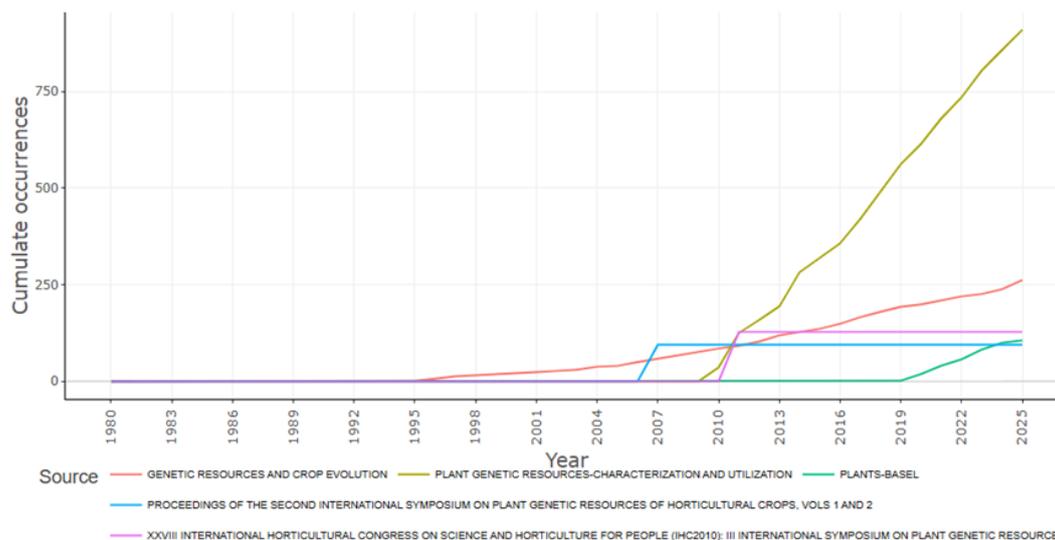


Figure 4. Cumulative occurrences of publications by source in Web of Science (1980–2025).

The most prolific authors are Singh M (50), Kumar A (45), and Maxted N (41). The top three institutions contributing to the field are the Indian Council of Agricultural Research (ICAR), the United States Department of Agriculture (USDA), and the ICAR–National Bureau of Plant Genetic Resources, reflecting their central role in global research production. At the country level, the highest number of publications comes from India, the USA, and Italy, with the world map further illustrating these nations’ leadership in biopiracy and plant genetic resources research. While these indicators reflect research productivity and geographical distribution, they do not directly represent the level of international collaboration, which would require a dedicated co-authorship or network analysis.

Keyword analysis shows that the most frequently used terms are genetic diversity (653), diversity (641), plant genetic resources (549), germplasm (380), and conservation (364). This indicates that research mainly focuses on genetic diversity, biodiversity conservation, and the sustainable management of plant genetic resources. The keyword “biopiracy” appeared 97 times (1%), suggesting that while it is not a dominant theme, it

has nonetheless gained increasing visibility in the literature. (See Figure 6-7).

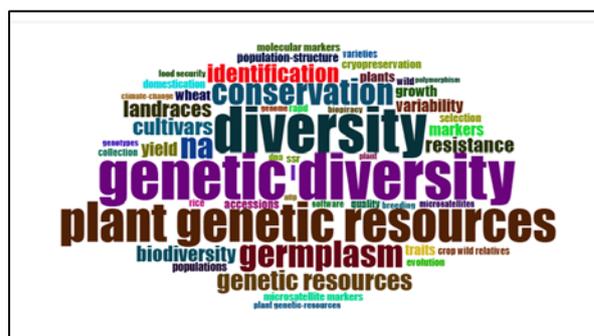


Figure 6. Word cloud of the most frequently used keywords in publications on biopiracy and plant genetic resources (1980–2025).

The bibliometric analysis revealed that publications on biopiracy and heirloom seeds have shown a rapid growth trend over the past 40 years, particularly after 2010, with an annual growth rate of 12.58%. The findings also indicate that studies are predominantly multi-authored

closely follow global trends and harmonize national regulations with policy recommendations outlined in international reports such as those of FAO, CBD, and IPBES.

In conclusion, the protection of heirloom seeds is not only about preserving a legacy inherited from the past but also about ensuring ecological stability, safeguarding future agricultural production capacity, and strengthening the global fight against biodiversity loss. This study contributes to increasing academic awareness of biopiracy research and provides a guiding framework for future interdisciplinary studies.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	B.M.Y.	H.K.
C	50	50
D	50	50
S	50	50
DCP	50	50
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50
PM	50	50
FA	50	50

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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A PERSPECTIVE OF INCORPORATING GIS IN WASTE COLLECTION IN INFORMAL SETTLEMENT TO COMBAT ILLEGAL DUMPING: SOUTH AFRICAN CONTEXT

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Abstract: Illegal dumping remains a persistent waste-management challenge globally, particularly in informal settlements of developing countries where municipal service delivery is inconsistent. In South Africa, inadequate and irregular waste collection has intensified the proliferation of uncontrolled dumping sites, creating substantial economic, social and environmental risks. This review synthesises existing empirical studies, policy documents and municipal case examples to examine the drivers of illegal dumping and evaluate the potential of Geographic Information Systems (GIS) to strengthen waste-management practices. A narrative review approach was adopted, drawing on literature sourced from Google Scholar, Scopus and Web of Science using search terms related to illegal dumping, GIS and informal settlements. Findings indicate that although GIS has been successfully applied internationally for hotspot detection, route optimisation and spatial monitoring of waste flows, its adoption in South Africa remains limited by insufficient datasets, technical capacity constraints, financial barriers and fragmented institutional coordination. Substantial disparities in waste-collection services between formal and informal settlements further exacerbate illegal dumping trends. The review identifies key opportunities for integrating low-cost, context-appropriate GIS tools to improve service delivery, facilitate proactive intervention and support evidence-based planning. Policy recommendations include establishing integrated geodatabases for informal settlements, expanding community-based reporting mechanisms and adopting GIS-enabled routing systems. Future research should prioritise predictive modelling of illegal dumping patterns and empirical assessments of GIS implementation across South African municipalities.

Keywords: GIS, Waste management municipality, Informal settlement, South Africa

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1. Introduction

Illegal dumping has become one of the biggest issues all around the world. It affects the living conditions in society, particularly the informal settlements of developing countries; thus, slows down the sustainable development of the country (Ogunmodede et al., 2014; Pacione, 2007). Pacione (2007) explains that the concept of sustainable development has been a challenge in many developing countries. Thus, finding it difficult to implement the measures of sustainability while still in the process of development, especially in urban areas where the majority reside in poor townships that are largely characterized by informal settlements.

South Africa is amongst the fastest developing countries faced with challenges of illegal dumping mostly in townships and in informal settlements found in

metropolitan (Ngeleka, 2010). According to Yoada et al. (2014), the local government is responsible for the provision of waste management services in the areas under its jurisdiction. However, Antwi (2008) corroborated that the low-income communities receive inadequate service as compared to more affluent areas. This pattern is further confirmed by recent neighbourhood-level evidence: Ngalo and Thondhlana (2023) found that illegal dumping remains prevalent in low-income South African communities despite environmental awareness, largely due to inadequate municipal services, inaccessible waste collection points, and socio-economic constraints. A study by Selani (2017) indicated that the main factors contributing to illegal refuse dumping are insufficient waste removal services, delays in municipal collection, lack of formal waste



systems in informal settlements due to inadequate roads, insufficient skips, and long travel distances to disposal points. As a result, waste is observed piled up next to the waste skips which ultimately gets scattered all over the surroundings (Ejaz et al., 2010; Bhattacharjee and Polas, 2018).

This makes it easier for people to just dispose of waste in vacant spaces, along the roadside, and around waste skips which creates economic, social, and environmental concerns (Nkwachukwu et al., 2010; Agarwal et al., 2015). The environmental impact of illegal dumping is significant with notable environmental challenges which adversely cause a vast growth in health-related issues within communities (Rahman et al., 2008; Sibanda, 2019; Sule et al., 2014).

Concerning all the above mentioned, waste management practices of illegal dumping are ineffective in informal settlements even though there are regulations related to waste management. Thus, improving illegal dumping practices requires effort and to make progress, institutions need to embrace technological interventions that are adaptive such as Geographic Information System (GIS) that can solve a variety of problems (McAllister, 2015; Amakihe, 2011). A large number of existing studies in the broader literature have examined the application of (GIS) and remote sensing to deal with the issue of illegal dumping. This has been explored by Jakiel et al., 2019; Jimoh et al., 2019) which noted a significant success in combating illegal dumping when implementing these technologies. Moreover, although research has illuminated the successful implementation of GIS for good waste management practice in developed countries, it is insufficiently explored in South Africa particular in townships and informal settlement and remains to be tested to provide viable solutions for illegal dumping.

This review aims to critically examine illegal dumping challenges in South Africa's informal settlements and evaluate how GIS-based approaches have been applied globally and can be adapted to the South African context. The scope includes legislative frameworks, current waste management practices, and technological opportunities for improving waste collection efficiency and monitoring illegal dumping.

This study adopts a narrative review approach rather than a systematic review, given its conceptual aim of synthesising policy frameworks, empirical findings, and technological trends related to illegal dumping and GIS applications. Literature was gathered through Google Scholar, Scopus, and Web of Science using search terms such as 'illegal dumping', 'GIS', 'informal settlements', and 'South Africa'. Sources published between 2000 and 2024 were included. Studies focusing on municipal waste services, GIS-enabled monitoring, legislative frameworks, and waste-management challenges in developing countries were prioritised, while engineering-focused landfill design papers were excluded. This approach allows the integration of empirical evidence, municipal

case studies, and conceptual analyses into a coherent synthesis relevant to South African waste-management realities.

2. The Emergence of Informal Settlements in Developing Countries

Informal (settlement) development is a dominant trend of urbanization in many developing countries, especially on agricultural land, private land and public space that lack public services (Fernandes, 2011; Menshawy and Salman, 2011). According to Msimang (2017); Ono and Kidoroko (2020), people continuously migrate to the cities in search of better opportunities to sustain livelihoods and ultimately the number of informal settlements increases, hence resulting in many and complex socio-economic and environmental consequences. Like many other countries globally, this has been observed in Kenya and Brazil. Thus, informal settlements are considered a threat to the sustainability and development of many countries. Ono and Kidoroko (2020) revealed that Africa is one of the most rapidly urbanizing continents in the world.

The majority of African people are residing in townships that are characterised with informal settlements that lack basic services. The emergence of informal settlements in most cities is distinct evidence of the powerful political influence that was governing in the past. This led to the degradation of natural resources, urbanization, and most importantly the change of the social systems of living that has segregated people according to difference socio-economic status (Myers, 2003).

Kenney (2011), Jiusto (2011), Chikoto (2009) and Mels et al. (2009) have recognized this in South Africa and corroborated that dating back to 1949, the apartheid era intensified a long period of discrimination against blacks, Indians and coloured people; creating the tensions of segregation and the challenges of social inclusion and environmental security. Thus, the upgrading of informal settlements has been complicated by the apartheid era even after apartheid was finally lifted in 1994. This is mainly because the apartheid spatial planning has not been reversed through spatial development framework. Kenney (2011) reveal that the lack of basic services has led to many problems in informal settlements, such as social well-being, environmental and economic issues within settlements. Since 1994, the government struggled to achieve a permanent solution to these problems even after the constitution was promulgated in 1996 in an effort to ensure better service delivery to all citizens (Muller, 2008). Still, the process of putting the concerns of the informal settlements at the forefront remains a complicated task.

3. The Challenges of Basic Services in the Informal Settlements

Impoverishment and lack of basic services are some of the factors that contribute to the existence of informal

settlements (Simiyu et al., 2018). These conditions are often exacerbated by the lack of resources and the insecurity of the residents. While basic services are usually provided by the government and are generally related to the areas of water, sanitation, electricity, and waste management. (Msimang, 2017). Waste management services are one of the most observed indicators that impact the informal settlement dwellers in both the developing and developed countries and such can be drawn as a global challenge (Williams et al., 2019). A study by Simiyu et al., (2018) in Kisumu, one of Kenya's informal settlements concluded that the lack of basic services in these settlements is a reflection of poor enforcement of policies. While Fernandes (2011) and Msimang (2017) assert that informal settlements are unplanned and unstructured which paves a way for the inability of basic service provision.

Tembon, (2012) noted that among waste management services in informal settlements, there's a lack of waste collection services. This is because of numerous factors that contribute to the lack of road access in many informal settlements. These include the lack of cooperation from the residents and inadequate financial means. This implies that waste collection trucks have no access to informal settlements making it challenging to collect waste. An example of this is observed in confronting informal settlements of Ghana at Accra and South Africa (Antwi, 2008). According to Chikoto, (2009); Ngeleka (2010); Makabeni, (2018) many informal settlements in South Africa including Kliptown in Soweto, Claremont in KwaZulu-Natal and Dunoon in Cape Town all have common waste management challenges. These include inadequate sewage disposal facilities, poor roads, and accumulation of solid waste by the skips. Furthermore, large volumes of refuse are left to litter the streets and accumulate in open dumps where flies, rats, rodents, and other disease-carrying insects' breed. Selani (2017), have also demonstrated that the informal neighbourhoods are faced with inadequate or lack of waste removal, which reflects patterns of social isolation and ultimately threatens the health of the public and the environment.

4. Waste Management Legislation in South Africa

Incorrect disposal of waste is covered at all three levels of government (national, provincial, and local) legislation and regulations in South Africa. Relevant sections of the spheres of government legislation and regulations are well documented in the constitution of South Africa Act 108 of 1996; National Environmental Management Act (NEMA) 107 of 1998, and the National Environmental Management: Waste Act 59 of 2008 (Abel, 2014). Zhakata et al., (2016) also assert that the enactment of the constitution enshrines democracy and human rights which are essential to making sure that everyone's interests and needs are addressed. Such needs include

waste management service delivery. Thus, as a supreme or higher law, its provisions provide a framework under which all regulations, legislation, institutions, and procedures operate effectively and efficiently.

Buso et al., (2015) and Nkosi (2015) adds that the constitution is at the centre of the political and social life of the country. It defines the relationship between the State and the society, and between the distinct functions of the State. Thus, each organ of state must ensure that the provision of services to communities are rendered in a suitable manner that provides a safe and healthy environment. Grangxabe et al. (2023) highlight that one of the most important purposes of the constitution is the bill of rights that guaranteed certain basic rights for its citizens. One of the basic rights stipulated in section 24 of the bill of rights is the right to a healthy and protected environment for the benefit of the present and future generations. It is however noted that a vast majority of South Africans in informal settlements live in environments that are harmful to their health and wellbeing, although albeit the purpose of the NEMA (Act No. 107, 1998: 1) provides for the establishment of principals in decision making in all matters that relate to environmental issues; institutions that will promote cooperation in the governance and the environmental functions of state organs and; enforcement and administration of environmental management laws and related matters. is to *"provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state; provide for certain aspects of the administration and enforcement of other environmental management laws, and provide for matters connected therewith."*

Therefore, National Environmental Management: Waste Act 59 of 2008 must equitably prioritise people and their needs by ensuring that the state efficiently tackles the challenges of pollution and unsustainability in informal settlements. Moreover, waste disposal is critical during the waste management processes of various municipalities, hence the need for more proactive governance and technological intervention regarding waste management (Zhakata et al., 2016).

According to the Department of Environmental Affairs (2013); Kidd (2011) and Zhakata et al., (2016), *"waste management is one of the critical elements of sustainable development primarily because sound waste management practices contribute to sustainability."* Conversely, Zhakata et al., (2016) argues that legislation regulating waste management legislation in South Africa has historically been fragmented and still is, to some extent. Kotzé, (2005) explains that this is because the line functions of the national, provincial, and local spheres work independently from one another, and governance across the spherical divides is also largely discontinuous. Ultimately, prevents the achievement of sustainable

service delivery. On the contrary, Kidd, (2011) describe that the coming into effect of the National Environmental Management: Waste Act (Act No. 59 of 2008) (NEM: WA), presents more holistic approaches to waste management regulation. This holistic approach is aimed at addressing aspects of waste management, which includes the unavailability of information relating to legal and illegal dumping sites. Substantial portions of the population are not receiving frequent and adequate waste collection service. The lack of these databases promotes inadequate regulation and enforcement of the legislation (DEA, 2011). Although the waste act is in place, most municipalities still find it challenging to efficiently implement waste management strategies (Kidd, 2011; Zhakata et al., 2016). Recent empirical work by Ntlangula, Xelelo and Chitongo (2025) further highlights these enforcement gaps, showing that illegal dumping persists largely because monitoring capacity is weak, enforcement is inconsistent across income groups, and municipalities lack sufficient resources to ensure compliance. Informal settlements often experience inadequate waste collection services, poor infrastructure and inconsistent municipal support, patterns also observed in other developing regions where irregular collection and uncontrolled dumping are common (Argun et al., 2015).

When viewed comparatively, South Africa's waste-management landscape reflects patterns observed across several developing regions, where legislation is well-established but implementation remains inconsistent. In contrast, countries such as Japan, Germany, and the United Kingdom maintain strict enforcement mechanisms, high collection frequencies, and advanced separation-at-source systems supported by strong institutional capacity. Similarly, many Latin American cities—such as São Paulo and Bogotá—demonstrate more structured integration of community recycling programmes and municipal monitoring tools. The divergence highlights that South Africa's challenges are not rooted in the absence of policy but in infrastructural inequalities, service-delivery fragmentation between formal and informal settlements, and limited technological adoption. This comparative perspective clarifies the structural drivers behind illegal dumping and underscores the need for integrated, multi-level governance reforms.

Consequently, to address the waste management challenges and realise the objectives of the NEM: WA, the DEA published the NWMS in 2012 in order to support the goals and objectives of the NEM: Waste Act. Furthermore, to the extent that the NWMS creates norms and set standards at the national, provincial and local spheres (Alberts, 2014), it encourages municipalities to include their Integrated Waste Management Plan's (IWMP) in their respective Integrated Development Plan's (IDP) for waste management services to be streamlined along with other basic services such as water, sanitation, electricity and housing (Zhakata et al., 2016). Table 1 shows the

existing waste management methods that are commendable but have not yet delivered the needed impact due to lack of proper execution, flexible approach, and weak technical enforcement. Although the objectives of the NEM: WA demand the desired sound waste management, the reality at present looks different because challenges with waste infrastructure and delivery of waste services and the problem of litter and illegal dumping are still visible. Therefore, there is an urgent need to adopt flexible approaches that promote better service delivery for communities.

5. Current Existing Practices of Managing Waste in Informal Settlement

Waste management involves generation, collection, handling, transfer, disposal, reuse, and recycling (Noiki et al., 2021; Demirbas, 2011; DEA, 2011; Dri et al., 2018). Waste management practices differ from one country to another depending on the waste sources, types, policies, regulations, and laws (Noiki et al., 2021; Coker, 2016). Numerous studies by Noiki et al., (2021); Ike et al., (2018); Agwu, (2012) and McAllister, (2015) identified that current waste management practices around the world are fast becoming unsustainable and leading to notable environmental risk; particularly in informal settlement. This is observed in the United States of America (USA), Japan, Zimbabwe, Kenya and including South Africa (United States Environmental Protection Agency, 2015; Stephen, 2014; Bhagwandin, 2013; Jerie and Tevera, 2014; Gutberlet et al., 2017; Mwangi et al., 2021 and Haywood et al., 2021).

According to the United States Environmental Protection Agency, (2015) and Chisadza (2015), the USA produces huge volumes of waste, Also Stephen, (2014) and Jakeni et al. (2024) identified that Japan generates waste worth approximately 50 million tons annually. Further that, Japan is faced with many challenges of illegally dumped waste. However, its government have implemented the reduction, reuse, recycling, and recovery method to manage the issue of illegal dumping. Bhagwandin, (2013) and Chisadza (2015), observed that in the USA, Australia, Canada and England waste is properly managed and stored in bags and transferred in large steel or plastic bins which are lifted mechanically by the compactor trucks to the waste transfer facilities. Nevertheless, Refsgaard and Magnussen, (2008) and Jakeni et al. (2024) assert that developed countries have advanced technology used for proper handling and management of waste. Thus, Sthiannopkao and Wong (2013) indicate that despite the copious amounts of waste produced in developed countries; its technology has progressed in terms of handling, storing, collecting, and transporting waste to the final destination that promotes sustainable environment.

Table 1. Enforcement strategies for effective compliance with NEM: WA.

Enforcement strategies for effective compliance with NEM: WA	Aim
National Waste Management Strategy	<ul style="list-style-type: none"> • The framework of eight goals, to understand the direction that waste management will take in the local government sphere. • Improve governance and enhance the effectiveness of public sector organisations and institutions. • Implements the Waste hierarchy. • Meets the social and environmental needs of the poor communities. • Runs awareness programmes in schools and municipalities about littering and illegal dumping.
Waste management norms and standards	<ul style="list-style-type: none"> • Requires that municipalities must exercise their executive authority to: <ol style="list-style-type: none"> i) deliver local waste management services. ii) perform their duties concerning waste services including i.e. waste collection. • Critical tools for achieving the objectives of the NWMS to: <ol style="list-style-type: none"> i) minimise the associated environmental impacts and financial costs associated with improper waste management. ii) provide for the negative impact of poor waste management practices on health and the environment within the area of jurisdiction of the municipality. iii) assist municipalities to set local standards for control of litter. iv) help with the implementation of the waste management hierarchy at a local level. v) Discuss issues of fiscal management and resource availability.
Integrated Waste Management Plan & Integrated Development Plan	<ul style="list-style-type: none"> • Deals with a variety of waste management service issues, including, i.e. collection of waste, types of waste collected, methods for waste collection, waste containers used and the frequency of waste collection.
City of Cape Town Metropolitan Municipality By-Laws and Enforcement	<ul style="list-style-type: none"> • Ensures that waste management services are appropriately budgeted for and provided sustainably and efficiently. • Monitor the compliance within waste service providers and generators. • Expanded Public Works Programme for cleaning of the illegally dumped material. • Appoints law enforcement officer to patrol for illegal dumping.

While Gutberlet et al., (2017); Mwangi et al., (2021) and Omollo, (2019) state that the waste situation in Kenya’s informal settlement depend on individual waste pickers, recycling groups and community-based organisations. This is because waste is mainly collected in the central business district and the main markets. Thus, waste generated in informal settlement remains uncollected and illegally dumped in vacant spaces and along the road, leading to appalling conditions in the neighbourhoods. Jerie and Tevera (2014) also noted that Zimbabwe is also contending with the same problem of waste that is collected daily in the city centre and markets but only collected once in the residential areas. Whilst there is little to no adequate removal of waste in informal settlement. This results to the residents dumping their waste illegally and practice open burning in uncontrolled environments.

Likewise, South Africa is no exception to this. Haywood et al., (2021) and Naidoo (2009) reveal that it is the duty of government municipalities to implement effective waste management services. Furthermore, various levels of service delivery are recognized in South African national waste collection standards, depending on the practicality

and cost efficiency in each area (DEA, 2011). Hence waste removal frequencies are put in place to avoid environmental and health risks. Haywood et al., (2021) suggest that “*containers must be removed within 24 hours of being reported full but at least once a week*”. Despite this, low-income area remains with waste uncollected and piled up along the roads, resulting to extensive littering and illegal dumping. A meta-analysis by Maphanga, Grangxabe and Madonsela (2025) reinforces this finding, demonstrating that informal settlements across South Africa consistently experience high waste-generation rates but extremely low collection coverage, reflecting systemic service-delivery inequalities that directly contribute to illegal dumping. Deficiencies in collection performance have been shown to accelerate environmental degradation, particularly in low-income neighborhoods, across different geographic contexts (Bayram et al., 2015; Bayram et al., 2019).

Literature has shown that within the City of Johannesburg, the majority of households have weekly waste collection, while the rest have less frequent collections (Chisadza, 2015; Rasmeni and Madyira, 2019). Furthermore, the current existing waste

management practices are done using curb side collection and collection points such as waste skips. In addition to the principal methods currently used, there are cleaning programmes such as 'Pikitup' designed for informal settlements to clean illegally dumped waste but are costly and inadequate. According to the Integrated Development Plan (IDP) of the City of Cape Town, the collection of waste in formal households is done on a weekly basis. While informal settlements receive a door-to-door collection and frequent cleaning services within the area.

However, Armitage et al., (2010) noted that majority of informal settlements in Philippi, Khayelitsha and Kosovo still experience waste overflows from waste skip that has not been collected for a long time. Van Oordt (2018) state that the cleaning services offered in the informal settlements to combat illegal dumping costs the City of Cape Town millions of rands, but illegal dumping still continues despite the financial costs, stringent penalties and the law enforcement in place. According to Viljoen et al., (2021) state that the Hantam municipality in the Northern Cape follows the onsite, offsite and curb side waste disposal practices to manage waste. However, the mostly used method is burning and litter and/or dumping in open spaces. The municipality implemented the plastic bag system for the removal of waste, but it is often not provided for the residents. Furthermore, the drop off points for collection are far and the residents are not willing to travel further thus opt for dropping the waste on open spaces. Viljoen et al., (2021) and Serret and Ferrara (2008) emphasise that the distance between the houses and waste collection points has a major negative impact on waste management. Consequently, Wang et al., (2018) suggest that multiple collection points close to houses plays a significant role for proper waste management practices. While Viljoen et al., (2021) further recommends that exploring different and innovative alternatives such as to "*locate, map and monitor uncontrolled dumpsite*" using advanced technology can help to combat the issue of illegal dumping.

A series of recent studies by Thompson et al., (2013); Shaikh, (2006); Zhu et al., (2007); Agarwal, Chaudhary, and Singh, (2015) has indicated that the current existing waste management system uses a manual way for record keeping, allocation of collection services and monitoring of waste. Each area under the jurisdiction of its local municipality is assigned waste collection days and waste depots that are a certain distance from the area. Furthermore, the waste collection vehicle starts at a designated time two-three times a week for its waste collection trip. The collection of waste is not done with an intent of fulfilling the means of the NEM: WA and the bill of rights; such that there are no improvements with the waste management issues even though there are measures and tools in place to alleviate waste issues. This has also been explored in prior studies by Abel (2014), Nkosi (2015) and Bhattacharjee and Polas, (2018) in the

case of South Africa. Nonetheless, there are several systematic approaches in the system but fall short of a comprehensive plan.

6. The evolution of GIS and its Adoption

The Geographic Information System (GIS) can be defined as a tool and/or system for capturing, storing, manipulating, analyzing, managing, and displaying spatial data (Scholten and Lepper, 1991; Pandey et al., 2013; Thompson et al., 2013; Amakihe, 2011; Jimoh et al., 2019). The GIS phenomenon was founded in the 1960s by Roger Tomlinson and was later explored as an advanced discipline (Goodchild, 2018; Tate, 2018; Maguire, 1991). According to Martí-Henneberg (2011), the first GIS data on land usage was collected and analyzed with an effort to manage the country's resources in Canada. Furthermore, by the 1970s to 1980s the concept of GIS evolved as many entities as possible in the industry saw its potential and was continuously integrated and commercialised with satellite imaging technology (Deakin, 2009 and Tate, 2018). Consequently, by the late 1980s, the focus on improving the usability of technologies as a single path finally emerged. Fazal (2008) and Amakihe (2011) agree, that GIS use was associated with static data, a long time and involved only a few specialized users. However, in the 1990s, a software company Environmental Systems Research Institute (ESRI) released ArcView, a desktop solution for mapping systems. Today, GIS can be used in a short amount of time to process data in a simple form that can be interpreted easily and still maintain the integrity of information processed. Thus, GIS offers spatial functions that aid in solving complex problems. Thus, the visualization of GIS data through the internet on google maps, google earth, and open street map has become widespread (Henry, 2009; Martí-Henneberg, 2011; Arsanjani et al., 2015). Thus, the adoption of GIS is heading into the millennium, and the technology has now reached private entities and governmental authorities for planning and decision making in various fields (Tate, 2018; Amakihe, 2011; Fazal, 2008).

7. From Traditional Waste Management To Integrated Waste Management

Historically, the waste management approach in South Africa and elsewhere has narrowly focussed on the collection, transportation, disposal and treatment of waste from a public health and service delivery perspective (Davies, 2009:159). As Davies (2009:159) notes, "this waste management's paradigm was dominated by local government legislative or policy framework with a myopic focus on collecting and disposing of waste without addressing waste from the source." According to Marshall, and Farahbakhsh (2013) this type of waste management was informed by an escalation of products in the modern economy that further induced waste generation particularly in urban

areas. It is thus from this background that a greater need for a more organised waste management system, based on modern engineering and technical administration is required to ameliorate environmental and health problems emanating from littering, indiscriminate dumping of waste in the municipal public open spaces. This type of waste management system was characterised by high bureaucracy and technical inputs with little involvement of local communities.

The top-down and technical approach to waste management came with a number of environmental, social and economic challenges. For instance, countries such as New Zealand were confronted with the cost and environmental effects associated with identifying suitable sites for waste disposal (Davis, 2009:159), a problem that has increasingly affected South Africa over the last 30 years. This is due to the fact that waste management in general and municipal waste management approach in particular, has not yet paid attention to addressing waste from the source (Ibid, 2009). With the advent of integrated or sustainable waste management concept, informed by the resurgence of sustainable development in the early 1990s, there is a need to explore how cutting-edge technologies such as GIS can be used to deal with waste management problems from the source. Historically, the waste management approach in South Africa and elsewhere has narrowly focussed on the collection, transportation,

disposal and treatment of waste from a public health and service delivery perspective (Davies, 2009:159). As Davies (2009:159) notes, “this waste management’s paradigm was dominated by local government legislative or policy framework with a myopic focus on collecting and disposing of waste without addressing waste from the source.” According to Marshall, and Farahbakhsh (2013) this type of waste management was informed by an escalation of products in the modern economy that further induced waste generation particularly in urban areas. It is thus from this background that a greater need for a more organised waste management system, based on modern engineering and technical administration is required to minimise waste management problems around informal settlements and public open space areas.

8. The Benefits of Using GIS

The main objective of GIS is to allow users to find answers to their questions and solve problems by presenting data in simple visual ways (Pandey et al., 2013). Thus, GIS optimizes the efficiency of decision making and planning, also providing efficient means for data distribution and handling while eliminating the duplication of data at the minimum cost (Pandey et al., 2013; Mlisa, 2007). The benefits of GIS can be classified into five categories as depicted by the table 2 below.

Table 2. Five categories of the benefits of GIS

Category	Description
Cost savings resulting from greater efficiency	Improves economic efficiency by increasing productivity i.e. labour savings and improving workflow (Fais, and Bonati, 1997; Pandey et al., 2013 and Martynova et al., 2019).
Better decision making	Deals with making better decisions about spatial relationship related to proximity, connectivity, and the overlay of methods. Spatial decision support systems (SDSS) are one of the GIS decisions making concept that allows information system technology to increase the effectiveness of decision makers (Mlisa, 2007).
Improved communication	Effective presentation of information through GIS-based maps and visualizations that assists in understanding and analysing problems and solutions across multiple disciplines (Pandey et al., 2013 and Martynova et al., 2019).
Better geographic information record-keeping	Organizes and stores valuable information and/or geographic data and make it accessible from anywhere, at any time (Pickering et al., 1993).
Managing geographically	Capable to select information by area or by theme and combine one data set with another, to analyse spatial characteristics of data, to search for particular features and monitoring of data (Jakeni et al., 2024).

9. The growth and development of GIS in South Africa

The role of GIS is increasing in developing countries due to ever increasing population growth, slow economic growth, depletion of natural resources, infrastructural planning, and service delivery (Mennecke and West, 2001). However, GIS is still limited in some parts of the African continent because of the challenges associated with the availability of updated data, sufficient data

storage and appropriate software (Sipe and Dale, 2003; Mennecke and West, 2001). The initial application of GIS in South Africa was discovered in the 1990s through the state institution; that is the “Chief Directorate Surveys and Mapping and the chief Surveyor General of South Africa” and is now noticeable growing in recent years.

The GIS technology is used by government departments, semi-private institutions, consulting entities and universities (Breetzke, et al., 2011; Das et al., 2010). Government departments such as the local municipalities

use GIS to address issues such as development planning, housing and infrastructure, disaster management, tourism, agriculture, and water resources management. According to Das et al. (2010), the City of Ekurhuleni municipality uses GIS to analyse and address the state of the province and its service delivery to the residents. While the City of Cape Town municipality implemented a geodatabase for electricity, property, and water services. It is important to highlight that even though many developments of GIS are taking place, it still remains limited and not optimally used in other sectors of concern such as waste management services. A comprehensive regional review by Shabani et al. (2024) similarly concludes that GIS and Remote Sensing applications in Southern Africa remain in their embryonic stage, constrained by limited datasets, insufficient technical capacity and financial barriers, which collectively hinder full integration into municipal waste-management systems.

Across international case studies, GIS adoption in developed countries is predominantly proactive—focusing on predictive optimisation, route planning, early detection of illegal dumping risks, and integrated decision-support systems. In contrast, developing countries tend to use GIS reactively, mainly for post-hoc identification of illegal dumping hotspots and basic mapping of waste accumulation. This divergence reflects differences in institutional capacity, data availability, and technological investment. The South African context aligns more closely with the latter, where GIS is available but applied in a limited, problem-responsive manner rather than as a strategic planning tool. This comparison underscores a key opportunity for South Africa to transition toward more preventive, data-driven waste-management practices.

10. The Contribution of GIS in Waste Management in Developing and Developed Countries

Waste management requires a lot of planning for the efficiency and effectiveness of proper waste disposal which is a crucial factor in waste management. Thus GIS offers a wide range of functions that can manipulate information concisely for a desired output such as planning transport routes and waste collection points (Wekisa and Majale, 2020; Kallel et al., 2016; Karadimas and Loumos, 2008), selection of areas suitable for waste disposal (Nishanth et al., 2010; Sivasankar and Rathinam, 2017; Karsauliya, 2013; Mohammedshum et al., 2014), locating new landfills and transfer stations (Kimwatu and Ndiritu, 2016; Basavarajappa et al., 2013), identifying potential illegal waste dumping areas (Zainun et al., 2016; Chu et al., 2013; Sule et al., 2014; Mihai et al., 2015; Jakiel et al., 2018; Tasaki et al., 2007; Seror and Portnov, 2018; Romeo et al., 2003; Jimoh et al., 2019; Glanville and Chang, 2015; Jagila et al., 2014; Kubásek, 2013). Also, GIS has the potential to monitor changes in the environment

such as climate, land use, environmental sensitive zones, population, and basic service delivery. Thus, GIS can add value to waste management by providing outputs for decision support, analyse and monitor waste management databases to improve waste management services while contributing towards sustainability of a country (Amakihe, 2011; Vaisgampayan, 2014).

11. Planning Transport Route and Collection Points

Waste collection is a crucial but most challenging stage in waste management system due to cost implications, capacity, and inaccessibility within areas (Wekisa and Majale, 2020). A series of recent studies (Malakahmad et al., 2014; Islam et al., 2016; Kallel et al., 2016) has indicated that the use of GIS application for collection and transport optimization can help with optimal usage of resources with low economic and environmental costs. The aforementioned studies were conducted in Tunisia, Malaysia and Bangladesh, following the ArcGIS network analyst method to improve the collection points and transportation of waste (Malakahmad et al., 2014; Islam et al., 2016; Kallel et al., 2016). The ArcGIS network analyst method optimizes the operation of existing systems and develops advanced techniques to design and evaluate new systems for proper route for collection (Malakahmad et al., 2014). The aim of the network analyst was to determine the time taken to drive from one route to another and the collection time taken for each route to achieve reduced collection time and the route selection that is more optimum. The studies concluded by asserting that the use of ArcGIS network analyst for the route optimization has shown reasonable improvement in length of the routes and travel time minimization. Similar GIS-based optimisation approaches have been successfully applied outside Africa as well. For example, Argun and Bilgin (2025) demonstrated that route optimisation aligned with zero-waste principles significantly reduced operational distance and fuel consumption in Türkiye, suggesting that comparable models could be adapted within South African municipalities facing logistical constraints.

While a promising method, the GIS algorithm has been discussed by Karadimas and Loumos, (2008) and Vijay et al., (2008) to facilitate with identifying the location and allocation of waste bins and finally support the transport route for waste collection. The significance of the GIS algorithm allows the triangulated irregular network model that provides flexibility to conduct a criterion of a down and upslope movement in relation to road network, the distance between the bin location and household (Shaikh, 2006). Thus, the criteria ensure proper location of bin that is easily accessible to each household and ease in transportation to collect waste. This was observed in Greece and India (Karadimas and Loumos, 2008; Vijay et al., 2008). Both above highlighted methods are intended to achieve economic and

environmental benefits; thus, travel time, distance, fuel consumption and pollutant emission reduced compared to the outcomes of the current existing used methods.

12. Selection of a Suitable Waste Disposal Landfill Site for Disposal of Waste

According to Nishanth et al., (2010) and Mandizvidza et al., (2020) waste that is collected, not recycled, or reused usually ends up at a landfill site. Mandizvidza et al., (2020); Kimwatu and Ndiritu (2016) noted that the final disposal of waste to a landfill site is a common method that is widely used in many countries. However, sin et al., (2016) note that the landfill sites have become unsustainable and have reached it carrying capacity of waste. Nishanth et al., (2010) and Basavarajappa et al., (2013) reveal that because of the above-mentioned reasons it has become a serious challenging task to find a suitable landfill site due to social and environmental parameters. As a result, sufficient geospatial data is needed. Literature shows the success implementation of GIS integrated with remote sensing techniques. This model used a multi-criteria evaluation method for site selection; this was observed in Ethiopia, India, Kenya, and Iraq (Nishanth et al., 2010; Sivasankar and Rathinam, 2017; Karsauliya, 2013; Mohammedshum et al., 2014; Kimwatu and Ndiritu, 2016; Basavarajappa et al., 2013; Mussa and Suryabagavan, 2021).

In addition, Kimwatu and Ndiritu (2016) explain that the use of GIS and remote sensing can integrate numerous factors that involves decision making for a suitable site selection. Mohammedshum et al., (2014) also adds that the combination of GIS and remote sensing have a significant importance for selection of a suitable landfill site because of both its advantages that are effective in solving problems. Consequently, the multi criteria evaluation method considers the proximity analysis in relation to road, settlement location, drainage network, land use and sensitivity of the area to come up with concrete results that can be classified as a high suitable area for the disposal of waste. Thus, Kimwatu and Ndiritu, (2016) state that landfill should not be situated in a vicinity where there are public transportation routes but must be located at a suitable distance from road network however still be able to facilitate the transportation of waste and reduce relative cost involved.

13. Mapping Illegal Dump Sites Using GIS Techniques

Several methods are reported in the literature to address the issue of illegal dumping and among those is the implementation of GIS that has shown success in helping to combat illegal dumping around the world. The use of GIS to can be drawn from a study conducted by Jagila et al., (2014) at Minna in Nigeria; through the use of Geospatial technology to analyse the spatial patterns of waste dump sites and the health hazards associated with

the observed pattern. The study adopted a proximity analysis model to determine the distance from the dumpsites to roads, rivers, and the built-up areas. Furthermore, the study concluded that the Geospatial technology helped in providing information system. The purpose of the model was to establish a system that will provide information about dumping sites in various districts, and to help with monitoring and management of these sites which eventually prevents environmental hazards and disease outbreaks. The selected model by the study sought for a site suitability for a waste segregation facility so that waste can be recycled thus to help with waste minimisations and sustain landfill space which is a genuine issue across the world.

Likewise, Jakiel et al., (2019) demonstrated that the spatial distribution of illegal dumping can help with understanding the variations on the environment. Thus, factors the management and monitoring system of illegal dumping. The study focused on determining the spatial and temporal changes of illegal dumping sites in one of the national parks in Poland using GIS for mapping. The study established that the distance from the roads and the field forest edge are the most crucial factors that control the distribution of illegal dumping. Jakiel et al., (2019) concluded by asserting that the outcome of the map produced reveal the sites and places that need special focus in avoiding further occurrences thus to help local authorities for better management. In addition, Glanville, and Chang (2015) also reported the importance of using GIS to assess the distribution of illegal waste disposal sites and ultimately map and monitor illegal waste disposal sites in Queensland, Australia. The study explored a GIS mixed approach in addressing a critical gap in the detection of illegal waste disposal sites.

While Tasaki et al., (2007) suggest that the focus should not be on the occurrence of illegal dumping but on the size of illegal dumping and that can be determined by the use of zoning to assist in the efficient surveillance against illegal dumping. Thus, the evaluation of zoning results reveals sites that have a higher potential for large illegal dumping, and this was implemented in Japan and yielded successful results since illegal dumping is often managed by cleaning it up. Romeo, Brown, and Stuver, (2003) argue and demonstrate that one of the crucial factors to consider when dealing with the issue of illegal dumping using GIS is to develop a model to predict the susceptibility of illegal dumping to informal settlements. This was implemented in Texas using a model builder utility of the ArcView spatial analyst extension. The model revealed that visibility, accessibility, and density are identifying key features that impact illegal dumping location choice. Thus, areas in close proximity to roads are likely to dump waste along roadside because of easy access.

Conversely Kubásek, (2013) state that GIS can be utilised on a mobile device. This was observed in the Czech Republic to report illegal dumping and overloaded municipal waste containers which contribute to reduce

environmental pollution. The mobile based application encourages the citizens to create a map of illegal dumpsites in their surroundings. As a result, the application allows both the community and the municipality to work together since the application is effective as a widespread platform for reporting and monitoring illegal dumping (Kubásek, 2013).

14. Limitations and Future Research Directions

This review is limited by its reliance on secondary literature and the lack of systematically collected municipal datasets on illegal dumping and GIS use. In addition, empirical assessments of GIS implementation in informal settlements remain scarce, making it difficult to evaluate the real-world effectiveness of proposed technological interventions.

Future research should include municipality-level empirical studies, evaluations of citizen-generated spatial reporting tools, and pilot testing of cost-effective GIS models tailored to resource-constrained settlements. Further work is also needed to strengthen datasets for illegal dumping hotspots, develop predictive modelling frameworks, and assess how institutional capacity shapes GIS adoption across municipalities.

15. Conclusion

Waste management across the world is a dynamic process in terms of collection and disposal. The scope of waste management differs in each country. In South Africa, it is the responsibility of the local municipality to ensure that services are rendered to its communities; however, the reality currently looks different because waste collection services are insufficient, resulting in waste piling up next to bins and people disposing of waste illegally, resulting in waste scattered throughout vacant spaces despite legislation mandating proper waste management. Literature shows that waste management in developed countries has improved from its current state. The evolution is backed by the adoption of the advanced technology such as GIS to address waste related problems. Even though GIS is still limited in some parts of the developing countries including South Africa, it has proven to yield positive results in helping to deal with waste issues more particularly with illegal dumping. An appropriate use of available technological advances within the financial means of the country and municipalities can provide the right solutions in waste management. Thus, increasing efficient collection mechanism, monitoring of illegal dumping and proper service delivery. Policy actions should prioritise the establishment of integrated geodatabases for mapping formal and informal waste flows, expansion of community-level reporting tools, and routine GIS-based monitoring of illegal dumping hotspots. Future research should evaluate cost-effective GIS models tailored to resource-constrained municipalities, assess citizen-

generated spatial data for monitoring, and test proactive GIS-enabled routing systems against conventional waste-collection practices. This review is limited by its reliance on secondary literature and the lack of systematically collected municipal datasets on illegal dumping and GIS use.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	X.S.G.	M.K.	T.M.	B.S.M
C	20	40	20	20
D	20	40	20	20
S	20	40	20	20
DCP	20	40	20	20
DAI	20	40	20	20
L	20	40	20	20
W	20	40	20	20
CR	20	40	20	20
SR	20	40	20	20

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declare that there is no conflict of interest.

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