Use of GIS for Digital Mapping and Spatial Analysis of Landfills: Case of the Settat Province in Morocco

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ABSTRACT
In Morocco, the population growth and changes in consumption and production patterns are increasing the amount of generated waste, particularly household solid waste. It is estimated at 6.9 million tons per year, of which 5.5 million tons in urban areas, with a ratio of 0.76 kg/inhabitant/day (Ministry of the Interior, national portal for local authorities, National Household Waste Program). In the absence of controlled landfills, this waste negatively affects living spaces and generates health and environmental problems. The province of Settat, which is affected by this scourge, inefficiently manages this household waste as in other regions, thus requiring improvement with the involvement of the actors concerned. This work involves the creation of a cartographic database of household waste in the province of Settat using a Geographic Information System (GIS). The analysis of the maps made, the observation of photos of existing landfills, and a diagnosis of the landfills in the Settat province have shown a direct negative impact on the different vital axes.

Keywords: household solid waste, uncontrolled landfills, environmental management, province of Settat, geographic information system.

INTRODUCTION

On a worldwide scale, the problem of waste management is common. The waste is considered to be worthless as well as a source of nuisance and pollution; therefore, it is disposed of as far as possible in landfills. (Apollinaire TINI, 2003; Durand, 2012). In Morocco, the uncontrolled landfill is the most widespread management method to the detriment of other methods such as composting and incineration. These landfills have negative impacts on humans and the natural environment (Mountadar et al., 2009). In order to remedy this problem, Morocco has initiated several steps and strategies to improve the environmental management sector through the adoption of several laws, notably Law 28-00 on waste management and disposal promulgated by Dahier No. 1-06-153 of 22 November 2006 and published in the Official Gazette No. 5480 on 7 December 2006. This law and its application texts (elaborated by the Ministry of Interior in collaboration with the Department of Environment) introduced planning tools in the solid waste sector and thus imposed the implementation of a national program of household waste PNMD. The main objectives of this program are:

- Protection and preservation, organization of the collection, storage, transport, treatment of waste, planning, information, the definition of responsibilities, control, and sanction.
- The construction of landfills and waste recovery centers for the benefit of all urban centers and the closure and rehabilitation of all uncontrolled landfills by 2022.

Nevertheless, despite all these provisions, it has been noted that the regulatory requirements
for solid waste management provisions have not been applied in some provinces. The province of Settat, located in the central northern part of the Kingdom, is part of the Casablanca-Settat region with an area of approximately 7220 km² and 634,184 inhabitants according to the 2014 General Census of Population and Housing (RGPH). It is composed of 46 local authorities. Except for the Commune of Settat, which has delegated the waste management service to a private company, all the other communes in the province manage their waste directly.

This work aimed to develop a diagnosis of the current state of affairs to highlight the problems arising from the current management of household waste in the province of Settat based on the design and analysis of a cartographic database.

MATERIALS AND METHODS

Geographic setting of the province

The province of Settat includes 5 urban communes and 41 rural communes grouped in 3 circles. It is bounded administratively by the provinces of Berrechid and Benslimane to the north, the province of Kalla-Sraghna to the south, the provinces of Fquih Ben Saleh and Khouribga to the east, and the provinces of Sidi Bennour and BenGrir to the west (Figure 1).

Climate

The province of Settat is characterized by a semi-arid continental type climate. Its summers are hot with temperatures from 35°C to 45°C and its winters are cold from 5°C to 15°C. Fluctuating from year to year, rainfall is low, amounting to about 372 mm in an average year (Ben Ouakkass et al., 2018).

Relief

The territory of the Settat province is characterized by a certain physical homogeneity. Indeed, two zones can be distinguished: Lower Chaouia, where the soils are Tirs, and Upper Chaouia, where there is a progressive decrease in fertile land. It is made up of limestone plateaus of an accident landscape, reinforced by the spreading of phosphate layers (Icole, 1964).

The geology of the province

The province of Settat belongs to the northwestern part of the phosphate plateau of the Central Moroccan Meseta. It is made up of folded and flattened Hercynian basement soils that outcrop to the north and southwest of the plateau (Ben Ouakkass et al., 2018).
Study approach

The approach taken for this study is presented as follows:

- **Data Collection:** Population of the province (High Commission for Planning HCP), the surface area of the commune, number of households, and Quantities of waste (Settat prefecture).
- **Retrieving the map of the communes of the province of Settat in shapefile form (SHP) from the Settat prefecture.**
- **After data collection, the information was mapped using ArcGIS 10.7.1 (GIS) software as follows:**
  - A georeferencing of the maps according to a North Morocco degree coordinate system.
  - Creation of layers to define the geographical delimitation of each circle within the province.
  - Combining the attributes (number of populations, number of households, the quantity of waste produced and collected, X and Y coordinates of existing landfills) with the geographical references for each commune.
  - Elaborating the maps of population, location of existing landfills, and the map of waste quantities produced.
  - Providing a layout necessary for each map containing a legend, orientation, a coordinate system, and an adequate scale.
- **The observation of the photos of existing landfills, the analysis of the maps produced, and a diagnostic of the current state of the existing landfills enable to highlight the current environmental situation in the province.**

RESULTS AND DISCUSSION

**Population**

Table 1 shows the distribution of the total population over all the communes making up the province of Settat, the number of households, the surface area of each commune, and the population density per commune. The integration of this information into the database made it possible to produce the population map (Figure 2).

The population is concentrated in the urban communes of each circle with 141,637 inhabitants in Settat (chief town of the former Wilaya Chaouia Ouardigha), 32,528 in Ben Ahmed, and 19,229 inhabitants in El Borouj.

**Household waste**

Uncontrolled landfills in the province are a source of pollution. They are located near cities and sometimes not far from water environments (wadis or groundwater). They produce the leachates that reach surface water and generate direct...
Table 1. Total population of the province of Settat (HCP Haut-commissariat au plan 2014)

| Circle          | Commune          | Population | Households | Area(ha) | Density (hab/ha) |
|-----------------|------------------|------------|------------|----------|-----------------|
|                 | Settat           |            |            |          |                 |
|                 | Settat           | 141637     | 32714      | 60       | 2361            |
|                 | Mzamza Janoubia  | 19576      | 3485       | 307      | 64              |
|                 | Oulad Sghir      | 13866      | 2528       | 213      | 65              |
|                 | Sidi El Aidi      | 13839      | 2562       | 202      | 69              |
|                 | Bni Yagrine      | 13031      | 2023       | 125      | 104             |
|                 | Guisser          | 14760      | 2272       | 103      | 143             |
|                 | Toualet          | 11976      | 1925       | 142      | 84              |
|                 | Settat           |            |            |          |                 |
|                 | Sidi Mohammed Ben Rahal | 10410 | 1813 | 224 | 46 |
|                 | Mzoura           | 9525       | 1855       | 282      | 34              |
|                 | Machraa Ben Abbou| 9355       | 1574       | 134      | 70              |
|                 | Oulad Said       | 9271       | 1798       | 226      | 41              |
|                 | Gdana            | 9084       | 1669       | 202      | 45              |
|                 | Rima             | 8949       | 1473       | 123      | 73              |
|                 | Lahouaza         | 7394       | 1368       | 125      | 59              |
|                 | Khemisset Chaouia| 5527 | 1058 | 78 | 71 |
|                 | TOTAL            | 298200     | 60117      | 2546     | 117             |
|                 | Settat           |            |            |          |                 |
|                 | Ben Ahmed        |            |            |          |                 |
|                 | Ben Ahmed        | 32528      | 7222       | 41       | 793             |
|                 | Sidi Hajjaj      | 20732      | 3399       | 153      | 136             |
|                 | Ras El Ain Chaouia| 14747 | 2757 | 130 | 113 |
|                 | Sidi Abdelkrim   | 14008      | 2273       | 131      | 107             |
|                 | Oulad Fares      | 12341      | 1947       | 183      | 67              |
|                 | N’Khilal         | 12306      | 2062       | 176      | 70              |
|                 | Mniaa            | 11789      | 1898       | 115      | 103             |
|                 | Sganna           | 10245      | 1560       | 192      | 53              |
|                 | Oulad M’Hamed    | 10187      | 1746       | 302      | 34              |
|                 | Bouguargouh      | 9539       | 1543       | 93       | 103             |
|                 | Sidi Dahbi       | 8703       | 1572       | 98       | 89              |
|                 | Oulad M’Rah     | 8697       | 1746       | 2        | 4349            |
|                 | Lakhzazra        | 8582       | 1513       | 109      | 79              |
|                 | M’Garto          | 8514       | 1585       | 282      | 30              |
|                 | Mrizigue         | 8376       | 1430       | 192      | 44              |
|                 | Ain Dorbane-Lahlaf | 8120 | 1451 | 80 | 102 |
|                 | Oulad Chbana     | 8081       | 1319       | 74       | 109             |
|                 | Oued Naanaa      | 6991       | 1308       | 92       | 76              |
|                 | Loulad           | 6049       | 1209       | 5        | 1210            |
|                 | TOTAL            | 220535     | 39560      | 2450     | 90              |
|                 | El Borouj        |            |            |          |                 |
|                 | El Borouj        | 19229      | 3841       | 35       | 549             |
|                 | Dar Chaffai      | 17454      | 2913       | 342      | 51              |
|                 | Bni Khloug       | 12930      | 2290       | 160      | 81              |
|                 | Oulad Freiha     | 11581      | 1838       | 179      | 65              |
|                 | Laqraqra         | 11419      | 1833       | 231      | 49              |
|                 | El Borouj        |            |            |          |                 |
|                 | Sidi Ahmed El Khadir | 9687 | 1404 | 201 | 48 |
|                 | Meskoura         | 7180       | 1113       | 222      | 32              |
|                 | Oulad Armer      | 6673       | 1081       | 179      | 37              |
|                 | Oulad Bouali Nouaja | 6507 | 1065 | 162 | 40 |
|                 | Sidi Boumehdi    | 5081       | 797        | 86       | 59              |
|                 | Ain Blal         | 4699       | 906        | 81       | 58              |
|                 | Oulad Fares El Halla | 3021 | 525 | 128 | 24 |
|                 | TOTAL            | 115461     | 19606      | 2006     | 58              |
negative impacts on public health and the environment (Khattabi et al., 2007). Figure 3 shows the location of the existing landfills in the province of Settat with three landfills in the Settat circle, four landfills in the Ben Ahmed circle, and only one landfill in the Elbrouj circle.

Table 2 summarizes the quantities of household waste produced, collected, and the collection rate by urban and rural areas in the province of Settat. A large amount of waste is found in the urban area because of the high density of the population in these municipalities.

Figure 4 shows the amount of waste generated in the province. The city of Settat ranks first in the production of household waste with a quantity of about 133 T/day, which represents 34% of the waste produced at the provincial level. The collection rate at the provincial level is about 58%, with a rate of 86% in urban areas and 2% in rural areas.
| Communes                        | Tonnage produced in T/j | Tonnage collected in T/j | Collection rate in % |
|--------------------------------|-------------------------|--------------------------|----------------------|
| **Urbain perimeter**          |                         |                          |                      |
| Settat                         | 132.682                 | 129.763                  | 97.80                |
| El Borouj                      | 73.476                  | 54.519                   | 74.20                |
| Ben Ahmed                      | 25.3                    | 18.697                   | 73.90                |
| Oulad M’Rah                    | 12.852                  | 11.207                   | 87.20                |
| Loulad                         | 8.591                   | 5.661                    | 65.90                |
| Ras El Ain                     | 1.21                    | 0.038                    | 3.10                 |
| Guisser centre                 | 0.98                    | 0.715                    | 73.00                |
| Oulad Said CENTRE              | 0.78                    | 0.428                    | 54.90                |
| **TOTAL**                      | 255.871                 | 221.028                  | 86.38                |
| **Rural perimeter**            |                         |                          |                      |
| Mzamza Janoubia                | 7.23                    | 0.04                     | 0.60                 |
| Sidi Hajjaj                    | 6.25                    | 0.03                     | 0.50                 |
| Ain Dorbane-Lahtaf             | 5.99                    | 0.04                     | 0.60                 |
| Dar Chaffai                    | 5.41                    | 0.02                     | 0.30                 |
| Sidi Abdelkrim                 | 5.04                    | 0.04                     | 0.70                 |
| Ras El Ain Chaouia             | 4.67                    | 1.14                     | 24.50                |
| Guisser                        | 4.40                    | 0.77                     | 17.40                |
| Oulad Sghir                    | 4.07                    | 0.02                     | 0.50                 |
| Bni Yagrine                    | 4.04                    | 0.00                     | 0.00                 |
| Bni Khloug                     | 3.93                    | 0.11                     | 2.70                 |
| Sidi El Aidi                   | 3.85                    | 0.01                     | 0.30                 |
| Toualet                        | 3.78                    | 0.00                     | 0.10                 |
| Oulad Fares                    | 3.67                    | 0.03                     | 0.90                 |
| N’Khila                        | 3.53                    | 0.04                     | 1.00                 |
| Oulad Freiha                   | 3.42                    | 0.02                     | 0.60                 |
| Sidi Mohammed Ben Rahal        | 3.33                    | 0.12                     | 3.70                 |
| Mniia                          | 3.31                    | 0.01                     | 0.40                 |
| Laqrqaqa                       | 3.19                    | 0.01                     | 0.30                 |
| Oulad M’Hamed                  | 3.10                    | 0.02                     | 0.50                 |
| Sidi Ahmed El Khadir           | 3.02                    | 0.01                     | 0.20                 |
| Sgampa                         | 3.01                    | 0.00                     | 0.10                 |
| Mzoura                         | 2.96                    | 0.01                     | 0.40                 |
| Bouguargouh                    | 2.90                    | 0.01                     | 0.50                 |
| Machraa Ben Abbou              | 2.88                    | 0.00                     | 0.00                 |
| Gdana                          | 2.72                    | 0.02                     | 0.70                 |
| M’Garto                        | 2.56                    | 0.01                     | 0.20                 |
| Sidi Dahbi                     | 2.55                    | 0.02                     | 0.70                 |
| Oulad Chbana                   | 2.55                    | 0.00                     | 0.10                 |
| Mrizigue                       | 2.54                    | 0.00                     | 0.10                 |
| Rima                           | 2.50                    | 0.02                     | 0.80                 |
| Lakhzazra                      | 2.48                    | 0.00                     | 0.10                 |
| Meskoura                       | 2.46                    | 0.01                     | 0.30                 |
| Oulad Said                     | 2.15                    | 0.33                     | 15.30                |
| Lahouzza                       | 2.15                    | 0.03                     | 1.20                 |
| Oulad Fares El Halla           | 2.06                    | 0.00                     | 0.00                 |
| Oulad Amer                     | 1.89                    | 0.01                     | 0.40                 |
| Khemisset Chaouia              | 1.69                    | 0.00                     | 0.00                 |
| Ain Bial                       | 1.54                    | 0.01                     | 0.40                 |
| Sidi Boumehdi                  | 1.32                    | 0.01                     | 0.40                 |
| Oulad Bouali Nouaja            | 0.92                    | 0.01                     | 0.60                 |
| Oued Naanaa                    | 0.10                    | 0.00                     | 0.30                 |
| **TOTAL**                      | 131.16                  | 2.96                     | 2.25                 |
| **TOTAL PROVINCE**             | 387.031                 | 223.984                  | 57.87                |
| Communes                  | Communal garbage bin (%) | Communal or private truck (%) | Other (%) |
|---------------------------|---------------------------|-------------------------------|-----------|
| **Urbain perimeter**      |                           |                               |           |
| Settat                    | 72.7                      | 25.1                          | 2.3       |
| El Borouj                 | 41.2                      | 33                            | 25.9      |
| Ben Ahmed                 | 10                        | 63.9                          | 26.1      |
| Oulad M Rhah              | 79.9                      | 7.3                           | 12.7      |
| Loulad                    | 65.6                      | 0.3                           | 34.1      |
| Ras El Ain                | 0.5                       | 2.6                           | 97        |
| Guisser centre            | 47.1                      | 25.9                          | 27        |
| Oulad Said CENTRE         | 21.8                      | 33.1                          | 45.1      |
| **Rural perimeter**       |                           |                               |           |
| Mzanma Janoubia           | 0.50                      | 0.10                          | 99.30     |
| Sidi Hajaj                | 0.40                      | 0.10                          | 99.50     |
| Ain Durbane-Laftaf        | 0.30                      | 0.30                          | 99.40     |
| Dar Chafta                | 0.10                      | 0.20                          | 99.70     |
| Sidi Abdulkrim            | 0.50                      | 0.20                          | 99.30     |
| Ras El Ain Chaouia        | 1.10                      | 23.40                         | 75.50     |
| Guisser                   | 11.30                     | 6.10                          | 82.60     |
| Oulad Sghir               | 0.40                      | 0.10                          | 99.40     |
| Bni Yagrine               | 0.00                      | 0.00                          | 100.00    |
| Bni Khlouj                | 0.60                      | 2.10                          | 97.30     |
| Sidi El Aidi              | 0.10                      | 0.20                          | 99.80     |
| Toualelet                 | 0.10                      | 0.00                          | 99.90     |
| Oulad Fares               | 0.40                      | 0.50                          | 99.10     |
| N’Khila                   | 0.20                      | 0.80                          | 98.90     |
| Oulad Freiha              | 0.20                      | 0.40                          | 99.30     |
| Sidi Mohammed Ben Rahal   | 0.30                      | 3.40                          | 96.40     |
| Mniaa                     | 0.30                      | 0.10                          | 99.60     |
| Laqraqra                  | 0.10                      | 0.20                          | 99.70     |
| Oulad M’Hamed             | 0.10                      | 0.40                          | 99.50     |
| Sidi Ahmed El Khadir      | 0.10                      | 0.10                          | 99.90     |
| Sgama                     | 0.00                      | 0.10                          | 99.90     |
| Mzoura                    | 0.20                      | 0.20                          | 99.60     |
| Bouguargouh               | 0.20                      | 0.30                          | 99.50     |
| Machraa Ben Abbou         | 0.00                      | 0.00                          | 100.00    |
| Gdana                     | 0.30                      | 0.40                          | 99.30     |
| M’Garotor                 | 0.10                      | 0.10                          | 99.90     |
| Sidi Dahbi                | 0.60                      | 0.10                          | 99.30     |
| Oulad Chbana              | 0.00                      | 0.10                          | 99.90     |
| Mrizigue                  | 0.00                      | 0.10                          | 99.90     |
| Rima                      | 0.30                      | 0.50                          | 99.20     |
| Lakhzaza                  | 0.10                      | 0.00                          | 99.90     |
| Meskoura                  | 0.30                      | 0.00                          | 99.70     |
| Oulad Said                | 6.10                      | 9.20                          | 84.80     |
| Lahouaza                  | 0.50                      | 0.70                          | 98.80     |
| Oulad Fares El Halla      | 0.00                      | 0.00                          | 100.00    |
| Oulad Amer                | 0.20                      | 0.20                          | 99.60     |
| Khemisset Chaouia         | 0.00                      | 0.00                          | 100.00    |
| Ain Bial                  | 0.10                      | 0.30                          | 99.60     |
| Sidi Boumehdi             | 0.10                      | 0.30                          | 99.60     |
| Oulad Bouali Nouaja       | 0.20                      | 0.40                          | 99.40     |
| Oued Naanaa               | 0.10                      | 0.20                          | 99.70     |
It should be noted that in the rural areas, the douars do not benefit from any services to manage the waste produced: organic waste is reused to feed livestock and the animal excrement is used as fertilizer. The broken metals, wood, plastic, and cardboard are used in the consolidation of dwellings and traditional ovens and hammams.

**Mode of disposal of household waste**

Table 3 shows how household waste is disposed of. The most important mode is the communal bin. The Figure 5 shows that the landfills in the province exist on the edges of agricultural fields and near houses, wells, chaâbas, thus causing visual nuisances, fire hazards, an increase in black spots, the affectation of soil fertility, loss of livestock, and degradation of the ecological value of certain natural sites. This situation thus causes several nuisances on the landscape aspect, as well as risks of contamination of surface and groundwater. Table 4 provides a description and diagnosis of the current state of landfills in the province of Settat.

![Figure 5. Photos of Landfills; (A) Settat, (B) Oulad, (C); (D) Guisser, (E) Ben Ahmed, (F) Oulad Mrah, (G) Loulad, (H) Ras el ain, (I); (J) El Brouj](image-url)
Informal waste recovery is an aspect of household waste management that is present in the Settat province, as well as in other areas (Makamté Kakeu-Tardy, 2018). Recovered waste is generally reused in two ways:

- For subsistence and livestock feed.
- For resale, which allows objects to be reintroduced into the economic circuit (for example, paper, cardboard, iron, cans, glass, plastic, aluminum, and rubber).

Sorting/recovery of waste is a sector that concerns the entire chain from the garbage cans and containers to the landfill. Thus, this activity, despite its defects, makes it possible to:

- Valorize a non-negligible quantity of waste.
- Reduce the volumes of waste sent to landfills.
- Recover non-biodegradable waste.
- Guarantee a source of income for many underprivileged families.

However, if this recovery is carried out by sorting and collecting waste at the source, the results in terms of recovery and especially in terms of preserving the health of the population would be greater.

**CONCLUSIONS**

This study has established the current mode of household waste management, which influences the environmental quality of the Settat province as well as directly impacts the population and the natural environment of the province. The results have shown the urgency to take the decision to move to the effective implementation of planning tools under the national household waste program PNMD and thus to consider the creation of waste transfer centers in the territory of the Settat province and an inter-municipal landfill that will only receive non-recoverable waste. A questionnaire, intended for the various administrations and the

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**Table 4. Diagnosis of the current state of landfills in the province of Settat**

| Circle     | Commune      | Area (ha) | The thickness of waste (m) | Diagnosis                                                                                   |
|------------|--------------|-----------|---------------------------|---------------------------------------------------------------------------------------------|
| Settat     | Settat       | 32.5      | 2.5                       | • Discharge 7 km from the center.                                                            |
|            | Guisser      | 1         | 0.5 – 2.0                 | • Landfill near the center of the town.                                                       |
|            | Oulad Said   | 0.2       | 1.0                       | • Landfill near the center of the town.                                                       |
|            | Ben Ahmed    | 6         | 0.5 – 2.0                 | • Landfill is located 5 km from the center.                                                   |
|            | Ras El Ain Chouaia | 2     | 0.5 – 2.0                 | • Landfill is located 2.5 km from the center.                                                 |
|            | Ouled M’Rah | 2         | 1.0                       | • Landfill is located 1.5 km from the center.                                                 |
|            | Loulad       | 0.5       | 1.0                       | • Discharge is located 1km from the center.                                                   |
|            | El Brouj     | 10        | 0.5 – 2.0                 | • Landfill is located 5 km from the center.                                                   |

However, if this recovery is carried out by sorting and collecting waste at the source, the results in terms of recovery and especially in terms of preserving the health of the population would be greater.

**CONCLUSIONS**

This study has established the current mode of household waste management, which influences the environmental quality of the Settat province as well as directly impacts the population and the natural environment of the province. The results have shown the urgency to take the decision to move to the effective implementation of planning tools under the national household waste program PNMD and thus to consider the creation of waste transfer centers in the territory of the Settat province and an inter-municipal landfill that will only receive non-recoverable waste. A questionnaire, intended for the various administrations and the
population concerning the modalities of sorting, collection, and recovery of waste from households to the landfill, is being prepared.

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