

Digital Mapping and Spatial Analysis of Quarries Using GIS – A Case Study of Settat Province, Morocco

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ABSTRACT

The province of Settat plays a key role in supplying the building materials that meet the needs of the province as well as the provincial construction and public work sectors. Indeed, the province is full of natural potential in raw materials and counts more than 109 quarries. This study aimed to build a quarrying database in the province of Settat to both characterize the materials mined and map the quarries through the Geographic Information System (GIS). This mapping allowed conducting the geographical distribution analysis of quarries by territorial unit and type of materials. The results revealed a predominance of carbonate quarries, especially in the Ben Ahmed circle. This distribution can be explained by natural, economic, and logistical factors characterizing the study area.

Keywords: geographic distribution; Geographic Information System; mapping; province of Settat; quarries.

INTRODUCTION

The province of Settat is located in the center of the Kingdom. It is part of the Casablanca-Settat mega-region; this region is characterized as the country's first multi-sector economic hub. The province is bounded to the north by the provinces of Berrechid and Benslimane, to the south by the provinces of Kalla-Sraghna and Rhamna, to the east by the provinces of Khouribga and Fqih Ben Salah, and the west by the province of El Jadida. The province covers approximately 7220 km², which represents 35% of the regional area [Ministry of the Interior, Wilaya of the Chaouia Ouardigha Region, Settat Province, 2013].

It comprises five urban communes and 41 rural communes grouped in three circles (Table 1) [Direction Provinciale de Settat, 2016]. The province is characterized by a semi-arid climate in the north, shifting to an arid climate in the south; the average rainfall is about 378.8 mm/year.

Geologically (Figure 1) [Bolelli, et al. 1959; Gigout, et al. 1965; Institut Géographique National

(France), Gigout, 1954], the province belongs to the structural domain of the Moroccan Meseta, characterized by a Paleozoic basement peneplain surmounted by a tubular alpine cover. It is bounded to the northwest by the coastal Meseta, to the southwest by the Rhamna Massif, and to the east by the phosphate plateau [El Bouqdaoui, 1995].

A certain physical homogeneity characterizes the territory of Settat province. Indeed, two distinct zones can be indicated: the lower Chaouia, an area of Tirs soils, and the upper Chaouia, characterized by a gradual decrease in fertile land; it is constituted of limestone plateaus of a rugged landscape, reinforced by phosphate layering [Icole, 1964].

The analysis of the digital terrain model of the province (Figure 2) shows a decreasing topographic gradient from east to west, varying between 870 m and 15 m:

- At the Phosphate Plateau level, altitudes vary between 600 m and 870 m;
- At the Rhamna Massif, altitudes vary between 200 m and 340 m;

Table 1. Administrative boundaries of the province

Province	Number of circles	Number of Caidats	Number of Communes		
			Urban	Rural	Total
Settat	3	13	5	41	46

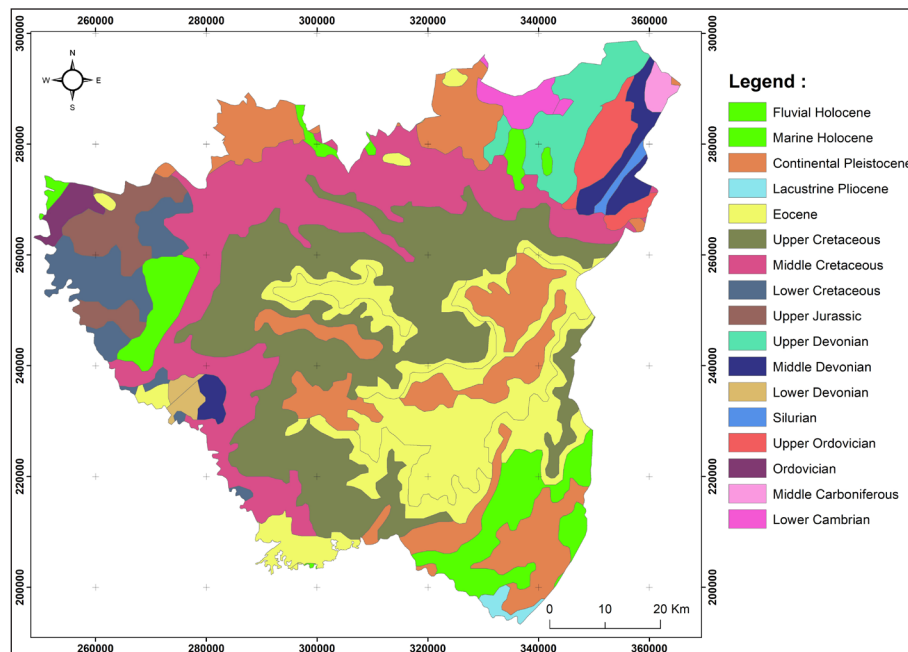


Figure 1. The geology map of Settat province

- At the coastal Meseta, altitudes range from 15 m to 300 m.

The exploitation of quarries has many impacts on the environment: irreversible soils and subsoil degradation (stripping, extraction, felling, earthworks, etc.), changes in landscapes and natural habitats, impact on biodiversity, dust emissions, vibrations and noise (explosives), greenhouse gases (transportation) or suspended materials (water resources) release, etc.

Due to the absence of an efficient legal framework before the release of Law No. 27-13 of June 9, 2015, relating to quarries [Dahir N. 1-15-66 of June 9, 2015 (21 Shaaban 1436) Promulgating Law N. 27-13 Relating to Quarries, 2015], the quarry sector has recently experienced dysfunctions concerning the modes of exploitation and the emergence of informal quarries, as well as the looting of materials and the ineffective control, which has had adverse effects on the population, the natural environment, the infrastructure, as well as the financial income [The Economic, Social and Environmental Council, 2014; Majdoubi, 2016] .

The goal of this work was to perform a situational analysis of the extraction of different materials in the province through [Aboutayeb, et al. 2013; Attima, et al. 2016]:

- the creation of a geographical database (Geodatabase) on opencast quarries in the province of Settat;
- the mapping of opencast quarries by material type and by commune using GIS;
- the analysis of the geographical distribution of the various opencast quarries.

MATERIALS AND METHODS

The data on open-pit quarries in the province of Settat comes from the inventory of quarries in the province conducted at the end of 2018 [Ministry of Equipment, Transport, Logistics and Water, Directorate of Administrative and Legal Affairs, 2018].

All the mapping work was carried out using the ArcGIS 10.5 software. The ArcGIS 10.5 software combines most of the functionalities related

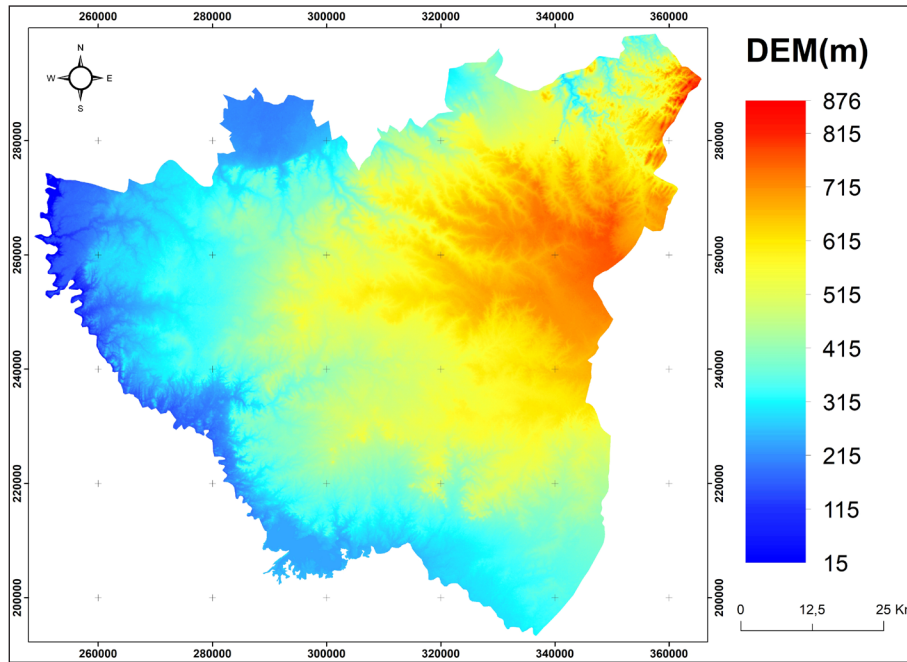


Figure 2. Digital terrain model of Settat province

to GIS. When used alone or combined with other applications, it can help conduct a project from data acquisition to presentation. Digitization, database management, spatial analysis, thematic mapping, and layout are tasks that can be carried out with ArcGIS 10.5.

There are two base maps used for these map representations. They showcase the boundaries outline of the three circles that make up the province of Settat. The boundaries of 46 provincial communes are also showcased.

The cartography was carried out by combining objects with spatial references and their attributes; it was necessary to link the attributes of quarries with the geographical references of each commune. The Geodatabase in question included two types of information:

- Attributes or alphanumeric information: this is the information collected from the administration regarding the type of material, area, and coordinates (X and Y);
- Geographical information on the territories of each commune.

A legend was built to demonstrate the proportional size of the number of quarries connected to each commune on the map. Most of the time, each card corresponds to a single field of activity. However, sometimes several neighboring areas are grouped on the same map. A scale to measure the distance from the province territory is expressed in kilometers.

RESULTS AND DISCUSSION

The database reported the distribution of quarries in the province of Settat by circle (Ben Ahmed, Settat, and El Broj) and by commune, while specifying the number of units, production capacity, and material type: carbonates, clays, pit-run gravel, massive gravel, alluvial aggregates, and shale.

Figure 3 shows the distribution of 109 quarries by material type in the three circles of the province. The analysis of this figure shows:

- The dominance of Ben Ahmed's circle with 92 quarries, equivalent to 84% of quarries within the province, followed by the circle of Settat with 11 quarries and the circle of El Broj with only six quarries;
- The dominance of carbonate quarries with 58 quarries, representing 53% of quarries within the province and 63% of the Ben Ahmed's circle quarries. Settat's circle has only one quarry of carbonates;
- The 16 clay quarries are in the Ben Ahmed's circle;
- Alluvial quarries are mainly in the circle of El Broj with six quarries. The Settat's circle has only one alluvial quarry;
- Massive gravel production is concentrated in the Ben Ahmed's circle with 11 out of 13 quarries in the province. The other two quarries are in the Settat's circle;

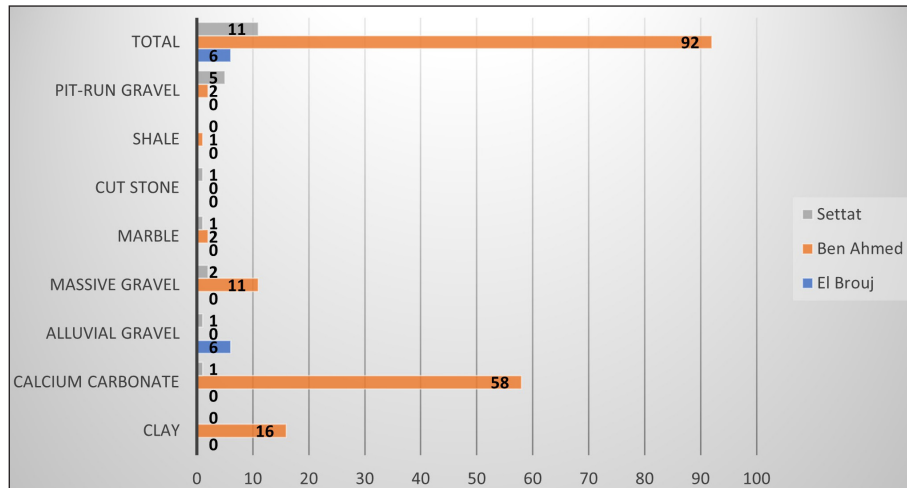


Figure 3. Distribution of quarries in the province of Settat by type of material and by circle

- The pit-run production of gravel mainly takes place in the circle of Settat with five quarries. The Ben Ahmed’s circle records only two quarries;
- The production of marble in the province of Settat is low with only three quarries: two quarries in the circle of Ben Ahmed and one quarry in the circle of Settat;
- The cut stones and shale are represented only by one quarry per type: a shale quarry in the circle of Ben Ahmed and a quarry of cut stones in the circle of Settat.

The spatial distribution of quarries represented in Figures 4 and 5 showed that the highest concentration of quarries is in the commune of Ain Dorbane-Lahlaf with 32 quarries, followed by the communes of Bouguergouh, Lakhzazra,

M’Garto, and Sidi Dahbi, with an average number ranging between 9 and 16 quarries. The rest of the communes have a very low number of quarries, between 1 and 8 quarries.

The spatial distribution of quarries by material type is illustrated in Figure 6, which shows:

- Alluvial gravel production (Figure 6a) is dictated by the Oum Errabiâ, which is a natural boundary between the province of Settat and the province of Rhamna. The province counts seven alluvial quarries distributed as follows: three quarries in the commune of Oulad Amer, and one quarry per commune in Ain Blal, Laqraqra, Oulad Freiha, and Machraa Ben Abbou;
- The production of massive gravel (Figure 6b) is determined by the proximity of consumption sites, which explains the exploitation of

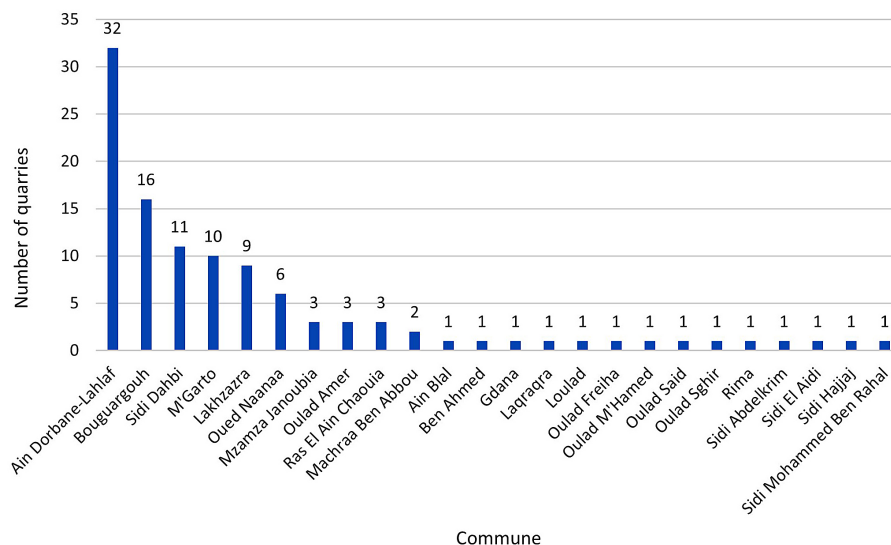


Figure 4. Distribution of the number of quarries

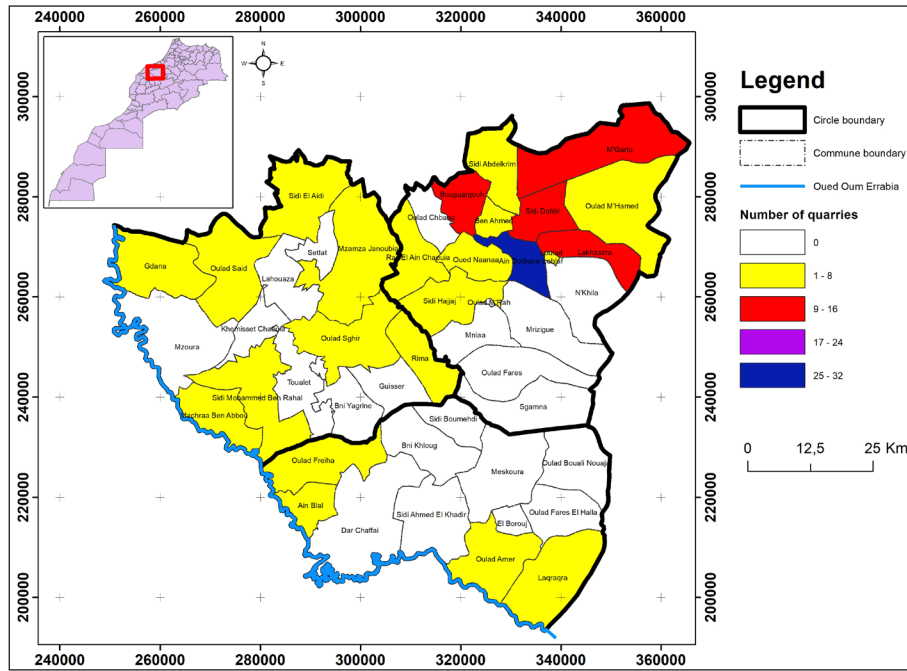


Figure 5. Geographical distribution of the number of quarries

- 9 quarries in the commune of M’Garto, initially planned for the construction of adjacent dams (Oued el Haiemer Dam and Tamesna Dam) and the construction of the Berrechid-Beni Mellal motorway. The four aggregate quarries are distributed, at a rate of one quarry per commune, in the communes of Oulad M’Hamed, Oulad Said, Ras El Ain Chaouia, and Sidi El Aidi;
- Calcium carbonate (Figure 6c) is mainly produced in the commune of Ain Dorbane-Lahlaf with 31 quarries. The neighboring communes located in the west of Ain Dorbane, Sidi Dahbi, and Lakhzazra come second with, 11 and 9 carbonate quarries, respectively. The commune of Oued Naanaa, bordering Ain Dorbane to the east, contains four quarries. Four communes each have a carbonate quarry in their territories. These are the Ras El Ain Chaouia, Loulad, Sidi Hajaj, and Oulad Sghir communes;
 - The clay deposits (Figure 6d) in the province of Settat are located in the commune of Bouguergouh with 16 quarries that supply the two cement plants, the brickworks, as well as clay ceramic units within the province;
 - Pit-run gravel (Figure 6e) can be produced everywhere in the province because these materials are mostly used without quality requirements. In the database used in this study, the pit-run gravel quarries are distributed as

- follows: Three quarries in the commune of Mzamza Janoubia and four quarries, at a rate of one quarry per commune, in the communes of Ras El Ain Chaouia, Sidi Mohammed Ben Rahal, Rima, and Sidi Abdelkarim;
- A single shale quarry (Figure 6f) in the commune of M’Garto. It supplies the cement plants in the region;
 - The province of Settat is not known by many marble quarries (Figure 6G). Three quarries are inventoried in the database: two quarries in the commune of Oued Naanaa and one quarry in the commune of Machraa Ben Abbou;
 - The production of cut stones (Figure 6h) is present only in the commune of Gdana with only one quarry.

The capacities of quarries vary in terms of production, ranging from one thousand m³ to more than one million m³ of material production per commune. For this reason, GIS was used to map the production capacity in the province of Settat by material type (Figure 7).

- The annual production of alluvial gravel in the province is 291000 m³/year over an area of about 2025025 m². This type of aggregate comes from deposits of unconsolidated materials, made up of sands and pebbles at the Oued Oum Errabiâ, in five communes (Ain Blal, Laqraqra, Machraa Ben Abbou, Oulad Amer, and Oulad Freiha). The analysis of

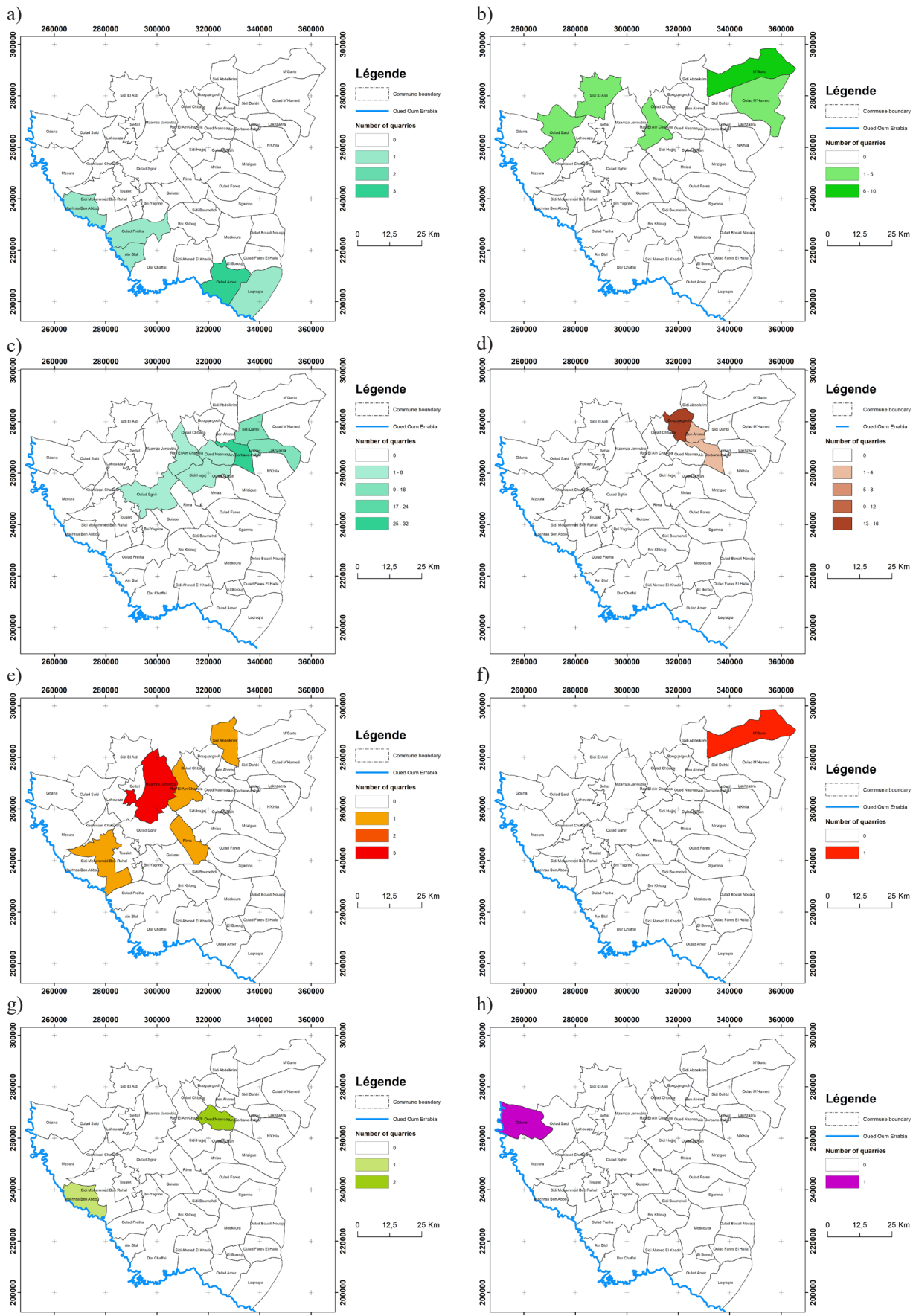


Figure 6. Geographical distribution of alluvial gravel quarries by commune (a); solid gravel quarries by commune (b), carbonate quarries by commune (c), clay quarries by commune (d), the quarries of all comers by commune (e), shale quarries by commune (f), marble quarries by commune (g), cut stone quarries by commune (h)

Figure 7a shows that the production capacity of the Ain Blal, Laqraqra, Machraa Ben Abou, and Oulad Amer communes varies between 15000 m³/year to 60000 m³/year. The commune of Oulad Freiha shows a higher production of 150000 m³/year;

- With an area approaching 1720645 m², the annual production of gravel amounts to 1.545 million m³/year (Figure 7b). The production, which is made from massive rocks derived from consolidated geological formation such as limestone, granite, or basalt is distributed among five communes (M'Garto, Oulad M'Hamed, Oulad Said, Ras El Ain Chaouia, and Sidi El Aidi). The highest production, 1.02 million m³/year, is recorded in the commune of M'Garto;
- The annual carbonate production in the province of Settat is around 1.195 million m³/year extracted over an area of approximately 2353720 m². It is divided into four classes: low, medium, high, and very high (Figure 7c). The analysis of this figure shows that the communes of Loulad and Ras El Ain Chaouia have a low production of 3000 m³/year to 10000 m³/year. The communes of Oued Naanaa and Sidi Dahbi have an average production of 37200 m³/year at 95500 m³/year. The communes of Ain Dorbane-Lahlaf, Lakhzaza, and Oulad Sghir have a high production of 95000 m³/year to 164050 m³/year. The highest productions are recorded in the commune of Sidi Hajjaj with an annual quantity of about 700000 m³/year;
- The annual production of clay amounts to 2657620 m³/year, on an area of around 2810782 m² (Figure 7d). It is distributed through three communes: the commune of Ben Ahmed with an average production of 150000 m³/year, the commune of Ain Dorbane-Lahlaf with a production of 1000000 m³/year and the commune of Bouguergouh with the highest massive production of 1511620 m³/year;
- With an area of 146000 m², the annual production of shale is about 150000 m³/year in the commune of M'Garto (Figure 7e);
- The production of pit-run gravel is in the order of 352729 m³/year, on an area amounting to 174090 m² (Figure 7f). The analysis of this figure shows that the commune of Mzamza Janoubia comes first with a production of around 150729 m³/year on an area of 40628 m²;

- The production of marble amounts to 11750 m³/year, on two communes. The analysis of Figure 7g shows a very high production in the commune of Oued Naanaa of around 10750 m³/year over an area of 44425 m²;
- The cut stones production is located only in the commune of Gdana with a production capacity of 600 m³/year on an area of about 30000 m² (Figure 7h).

On the basis of the results obtained, expressing the distribution of quarries in the province of Settat, it appears that the distribution of quarries significantly differs from one area to another. It is characterized by a high concentration in the circle of Ben Ahmed. The geographical distributions of quarries, as well as production capacity, are affected by two significant factors:

- Natural Factors: hydrological (Oued Oum Errabiâ) and/or geological characteristics of the commune (massive rocks, carbonates, clays ... etc.);
- Economic and logistical factors: construction of significant projects (dams and highways) or the presence of material-consuming industries (cement factories, Brickworks, and Ceramic Units).

The concentration of quarries in some areas of the Settat province can have environmental impacts on the air, soil, water resources, fauna, and flora of the territory. In this respect, and to address these kinds of problems, it is recommended to:

- Follow up on this study with an environmental assessment study of quarries, particularly on agricultural soils, underground and surface water resources, and air (greenhouse gas emissions and olfactory nuisances);
- set priority directions, including:
 - enhancing the use of materials not derived from quarries;
 - rationally using materials;
 - fighting against illegal exploitation;
 - optimizing the choice of quarry sites, and how they are operated to respect the environment.
- track and control quarry operations throughout the quarry lifecycle: from the application for exploitation to its rehabilitation.

It should be noted that as stipulated in the new law no. 27-13, most of these points will be addressed as part of the development of the regional quarries master plan. This scheme is designed to ensure better resources management by defining

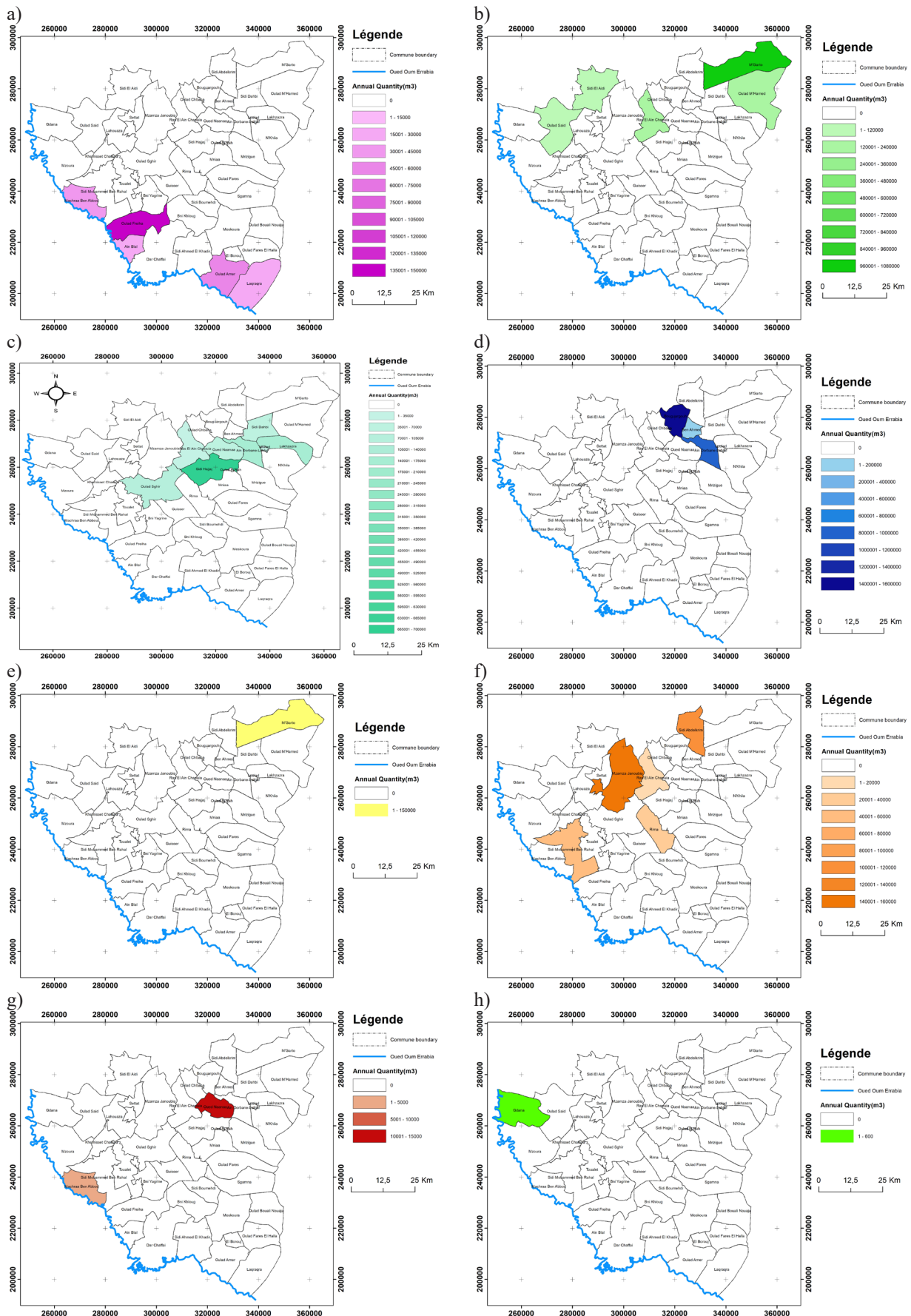


Figure 7. Geographical distribution of the production capacity of alluvial gravel quarries by commune (a), solid gravel quarries by commune (b), carbonate quarries by commune (c), clay quarries by commune (d), shale quarries by commune (e), quarries of all comers by commune (f), marble quarries by commune (g), cut stone quarries by commune (h)

the general conditions for quarries implantation in the province. As such, it will aid the decision-making of the administration when an application for a quarry is presented.

CONCLUSIONS

Through this study, several maps were produced dealing with the spatial distribution of quarries by materials in the territory of the Settât province. This review was able to highlight the key elements behind the development of construction material extractions in the province as well as indicated the most concentrated and productive areas. This study will form the basis of an environmental assessment of quarrying in the province, mainly since most of the quarries were operated under archaic regulations of 1914, modified in 1917 and 1929.

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