ISSN No:-2456-2165

The Role of Clay Quarries in Moderating the Effects of the Floods of 20 September 2020 in the City of BNI Hassen (Sayala basin)

Azaiez Naima[1,2,3], Zoghlami Karima[4,5] & Nawal Qhtani[1]
[1]King Khalid University, Faculty of Human Sciences, Abha, Saudi Arabia.
[2]Preparatory Institute for Literary Studies and Human Sciences of Tunis I (IPELSHT), Tunis.
[3]Research Laboratory: "Biogeography, Applied Climatology and Environmental Dynamics" (BICADE)
[4]Faculté des Sciences de Bizerte, Université Carthage
[5]Research Laboratory : Laboratoire des Ressources Minérales et Environnement (LRME), Université Tunis el Manar

Abstract:- The subject of mining and the spread of open-pit clay quarries in relation to the problem of flooding has generally been treated in a causal sense. Generally, the extraction of useful substances leads to a disturbance of the ecosystems, even if the contractors commit themselves to meeting the standards and criteria indicated in the contract specifications during the exploitation and rehabilitation phases. During the last two decades, flooding has become more frequent and severe in the agglomeration of Bni Hassen. The residential areas have invaded the majority of the land previously subject to the overflowing of streams and floods. For their part, the structures of "maskats" held upstream by a system of "Mgouds" and "Rabtas" are no longer capable of capturing runoff water as before. Despite the dredging of the bed of Wadi Sayala and its channeling in 2019, the floods of September 20, 2020, have caused loss of life and considerable damage to property, including infrastructure and agricultural land. This disaster could have been much more serious and its consequences heavier on the inhabitants if it had occurred outside the context of the exploitation of useful substances. In fact, the excavation pits played the role of real retention basins that surround the convergence zone of Wadi Sayala and Wadi Gamgoum. The study area had more than 29 mining pits with a depth between 5 and 47m. The objective of this research is twofold. First, to study the manifestation of the flood of September 20, 2020, in the watershed of wadi Sayala. Then, to make an estimate of the volume of water retained in the pits, which will be at the end the subject of a classification in term of storage and infiltration. This study shows that the total volume of runoff was reduced by 18% thanks to the presence of extraction pits.

Keywords:- *clay quarries, hydrological modeling, risk of flooding, hydrosystem of the Sayala wadi.*

I. INTRODUCTION

The damaging effects of the latest floods that occurred in the axis of the cities Moknine- Beni Hassen on 20 September 2020, served as a model to study in detail the direct and indirect causes that combined in the watershed of Wadi Sayala(Fig. 1). It is a hydrosystem that has been recently disturbed by many factors including the effects of mining and careless human settlements in the major bed and at the convergence of three watercourses, resulting in the particular susceptibility of the city of Bni Hassen to flooding as a direct result of the transgression of the laws of nature. Indeed, the upstream part (north-west) of the hydrosystem of sebkhat El Moknine constitutes a preferred place for the extraction of useful mineral substances especially the twenty-meter-thick clays attributed to the Miocene (Lachaal et al, 2013). These greenish to greyish clays are largely composed of illite and Kaolinite. They have a good chemical composition that is very favorable for the manufacture of bricks.This research work is aimed at developing a strategy for the optimization of pits and quarry discharges with a view to protecting the soil, managing water resources and protecting the town of Bni Hassen and the surrounding settlements from flooding. Through modeling and detailed statistical analysis of daily and annual rainfall data, the aim is to develop an advantageous solution of water substitution for the agro-pastoral sector and to optimize the capacity of the storm water management structures upstream of the city of Bni Hassen. In the context of the prevailing climatic changes, it becomes necessary to rethink the water management strategy within the framework of a more adapted management system. The results obtained from this research have shown that the quarry pits have retained more than 1950 m^3 of rainwater expected to flow to the city of Bni Hassen to reach Sebkhat el Moknine in the end. This estimate will be subject to uncertainty induced by the lack of direct measurements on the part of the infiltrated water and because of the less irregular topography of the bottom of the pits.

ISSN No:-2456-2165

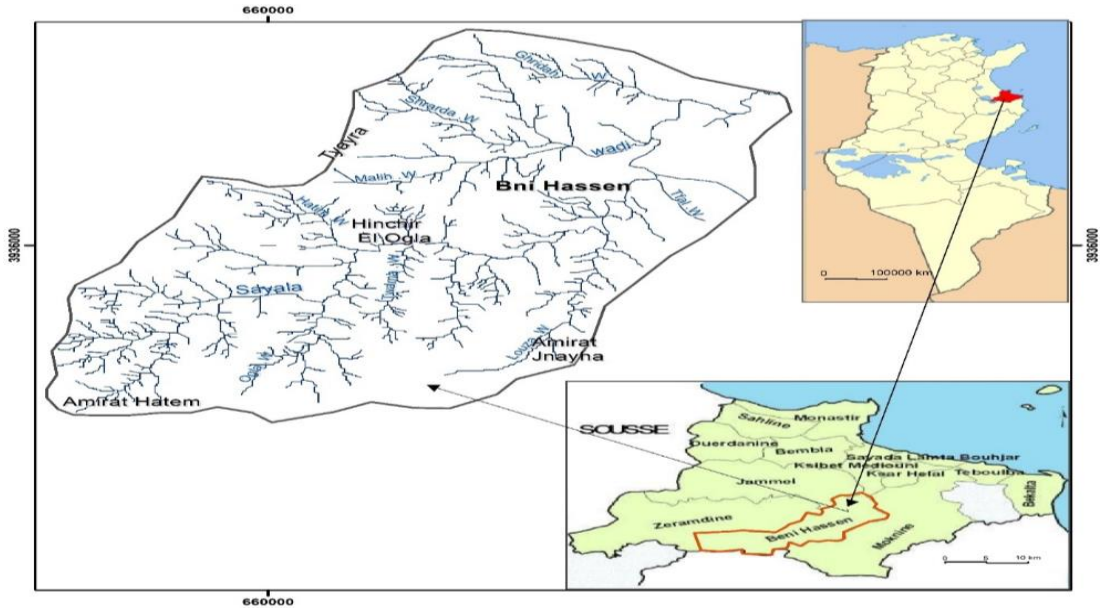

Fig.1: Location map of wadi Sayala

II. STUDY AREA

The region of Bni Hassen is part of the Central Sahel. It is located in the steppe area downstream of two hills: the hill of Zarmdine which culminates at 131 m and the hill of Amirat Hatim with an altitude between 145 m and 164 m. It takes the form of a strongly dissected erosion plain.The pedogenesis of the study area is dominated by a lithology characterized by the succession of limestone, marl that is more or less gypsum, coarse and fine sands, and silt and clay (Fig.2).

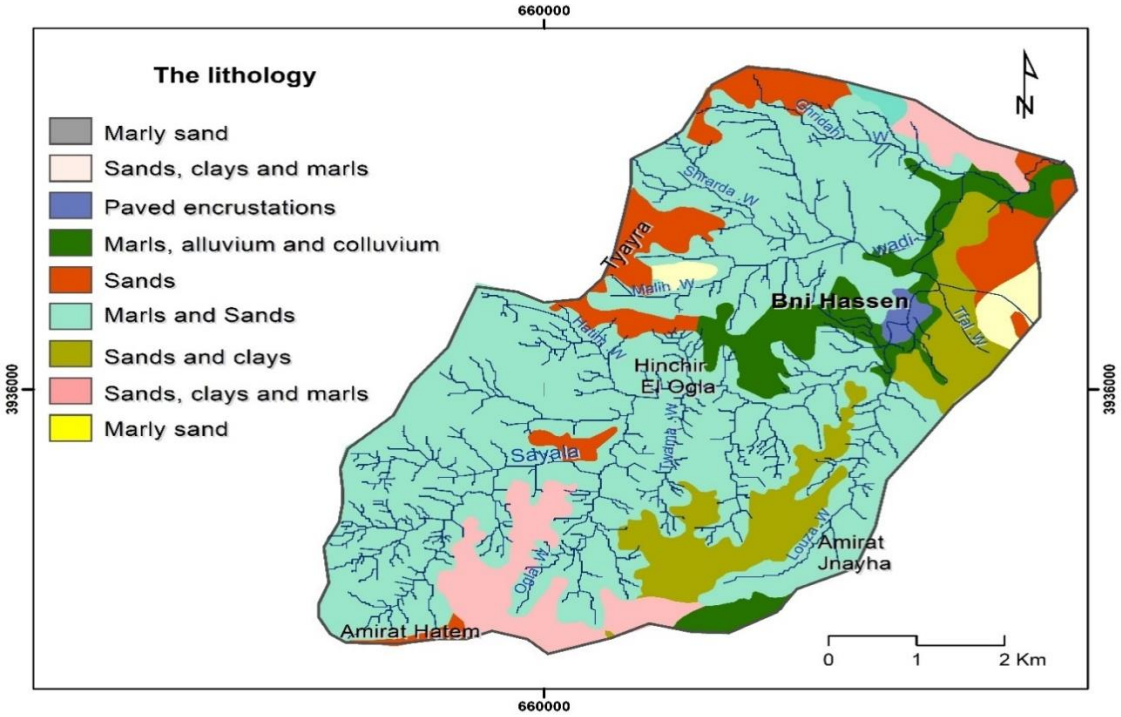

Fig. 2: Lithological map of the Sayala basin

Vertical movements of limestone, gypsum and salt are very frequent, coming first from the parent rock, but also by the capillary rise following the very intense evaporation (Abdelkhalek, 2009). Being part of the lower semi-arid zone with an average annual temperature of 18.2 °C, the region receives 312 mm of rainfall on average, although it received 180 mm during a single shower on September 20, 2020, which is more than half the annual rainfall. Although rainfall amounts are low, the recorded intensities are among the highest in the country due to the region's exposure to disturbances from the eastern Mediterranean basin in the form of eastern return flows. The small watersheds of the western bank of the sebkha of Moknine have a notable sensitivity despite the moderate altitudes that do not exceed 176 m in extreme cases and the slopes are among the lowest (Fig.3).

ISSN No:-2456-2165

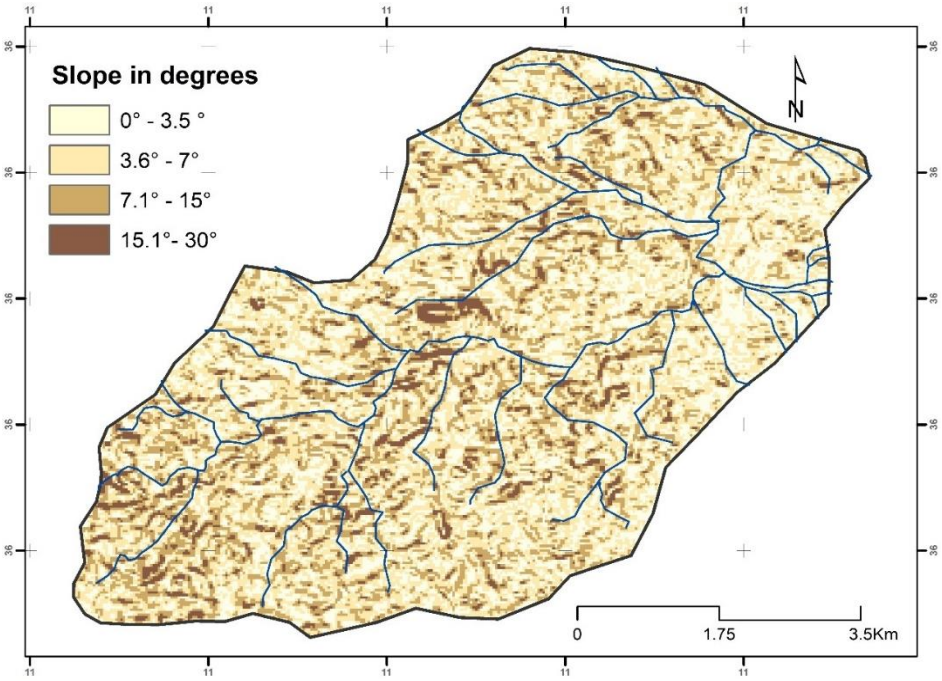

Fig. 3: Slope map of Sayala basin (SRTM Image)

The hydrographic network is not very developed, however, the region reacts quickly to runoff because of the low infiltration in the predominantly clay areas. The hydrological response is even more dramatic than in the past considering global changes. The effects of flooding were less felt by the population of hamlets 5 decades ago, because the overflow of the watercourses most frequently engulfs agricultural land and human life is rarely threatened. The recently extended cities in saddles and on both sides of the rivers or even at the convergence of two rivers are more and more at risk of flooding, especially during potentially torrential rains. The city of Beni Hassan is a representative example of this situation. The geological context of the Beni Hassan-Zarmdine-Ghnanda axis favors an intensive mining activity based on the exploitation of clays with geo-chemical characteristics that are very profitable in the brick industry. The level of exploitation can reach a depth of 54 m and even 57 m in saddles without taking into consideration the thickness of the surface formation and the soil. The majority of the quarries are exploited in the form of pits descending in steps towards the city of Beni Hassen, with more than 29 open pits. This exploitation began at the end of the last century, and has accelerated since 2010 as a result of the multiplication of brick factories opened in the center of the great Sahel olive grove. As a result of this intensive mining, the region has seen a destruction of nearly 60% of the Maskas works that constitute an ancient "participatory tradition". In the past, this system seemed well adapted to the geological, topographical, morpho-pedological and climatic contexts of the Central Sahel (Ennabli, 1993; Zarrad et al, 2010; Ben Salam et al, 2013). At present, a detailed study of the behavior of "meskats" and quarry pits will be necessary in order to give new explanations about the flooding and the possibilities proposed for the protection of the city and to highlight the enormous quantities of water that are lost in the sebkhat of Moknine.

III. METHOD AND TOOLS

The method and tools proposed in this research are of flexible use, based on data collection, spatio-temporal analysis of the rainfall of 5 September 2020 in terms of intensity, distribution and modeling. It was important to calculate runoff and establish an inventory of quarry pits to highlight the qualitative and quantitative aspects of flooding in the city of Bni Hassen. The mapping of the quarry sites on the DEM has helped to determine the degree of curvature of the pits and the order of their distribution in depth to finally calculate the volume of water that each pit can store.

The numerical simulation of the depth and volume of water is done using the Webinar function under the Surfer program and verified under Arc Gis using the "Geometry zonal as table" function. It takes into account the complexity of the geometric shapes of the pits and the irregularities of the bottom which are beyond 1 m. Therefore, the margin of error of the calculated depth will be 1 m less. That is to say, the estimated volume of water stored will be underestimated compared to the reality if we take into consideration this margin of error and the fraction of infiltrated water and the evaporated one.

The present modelling gives an idea of the degree of desiccation of the landscape and allows understanding the structure and spatial arrangement of the pits, which will necessarily have an effect on the change in the direction and velocity of the flow of Wadi Sayala and its tributaries.The Central Sahel region, located in the circle of Teboulba, Moknineand Bni Hassen, recorded rainfall between 108mm and 238mm whose epicenter was centered on the city of Bni Hassen and its watershed with 238mm or 4.38 times the normal amount of the month and 88.7% of the annual total (Figs. 4,5).

ISSN No:-2456-2165

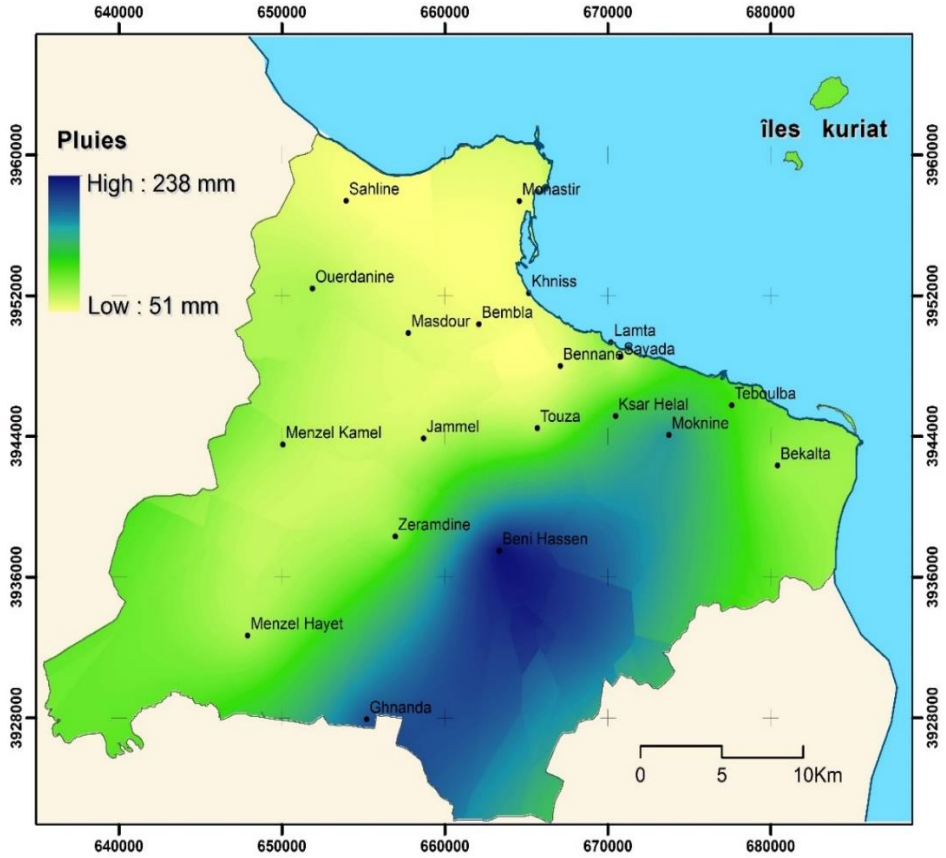

Fig. 4: Spatial distribution of the downpour of September 20, 2020, in the governorate of Monastir

(Source: DGRE, governorate of Monastir, 2020).

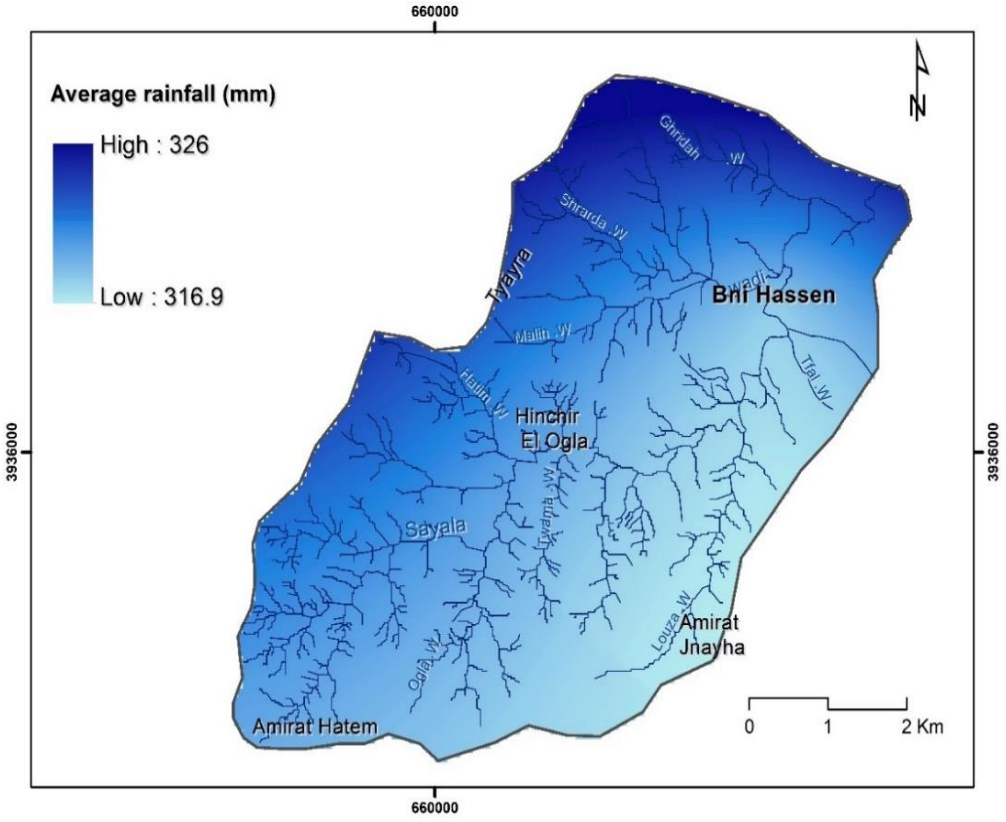

Fig. 5: Average annual rainfall in Sayala Basin

ISSN No:-2456-2165

These torrential rains fell on the region during a few hours (DGRE, governorate de Monastir, 2020). These torrential rains are due to two associated facts, first, a convective air mass followed by a drop of cold air in altitude and remains a frequent phenomenon in this region. These two facts are at the origin of the majority of the floods which are still in the collective memory of Tunisians. Several streams coming from different directions flow towards the city of Bni Hassen, including the most important wadi El Ogla, wadi El Gamgoum, wadi Hatim, wadi Twama, wadi Tfal, wadi el Gandoul, wadi Louza, wadi Sagtar, wadi Shrarda, wadi El Malih et wadi el Ghzela. Taking into account the land use, lithology, slope and distribution of quarry pits, these streams have experienced a very rapid hydrological response. Despite the modest altitudes, the rainfall on the hills is quickly drained by running down the slope and is concentrated in the districts of the city of Bni Hassen (Fig. 1).The first step in the hydrological analysis will be a spatial delimitation of the areas generating runoff, and then an estimation of the height of the runoff according to the rainfall amounts of the 20/9/2020 shower (Fig. 6).

Through the modeling, a comparison is sought between the distribution of the water runoff before and after the acceleration of the exploitation of useful substances in the region. Two scenarios were examined, the one of the September 20 floods and the other one based on the orthophotos of 2000 and under normal rainfall conditions and at the beginning of the mining phase.

This second modeling is made on the basis of a DEM on which all the excavations of the clay quarries have been eliminated to estimate the water runoff that could have reached the city under such rainfall conditions. The main objective is to determine the direct conditions which were at the origin of the floods and to simplify the design of a flood forecasting model adapted to the region of Bni Hassen and its surroundings. To get a better idea of the water runoff in the city, it is essential to calculate the time of concentration of the main tributaries of Wadi Sayala. This index is deduced in this case by empirical formulas, knowing that field measurements give more reliable results and given that the notion of soil moistening is essential. The Kirpich formula, developed in 1940, was chosen for the calculation of the runoff concentration time because the formula is suitable for small to medium sized catchments with a slope between 3 and 12% and predominantly clayey soils and clayey underlying bedrock (Kirpich, 1940; Azaiez, 2016, Azaiez et Ansar, 2022).

All these conditions are almost met in the case of the Sayala watershed. The formula is expressed as follows:

$$Tc = \frac{0.000325 \times L^{0.77}}{S^{0.385}} [1]$$

With:
Tc = Concentration time (h)
L = maximum length of the water course in the watershed (m)
S = average slope of the flow (m / m)

It is indeed a fairly short concentration time (1 hour and 16 min). This is sufficient to cause catastrophic flooding during occasional rains like those of 2016 and 2020. Indeed, the time of concentration varies from one tributary to another depending on the above-mentioned conditions. But this time of concentration is even more serious when the permeability decreases. This permeability remains dependent on the texture of the soil, the clay parent rock and also on the distribution of the quarry pits.

- **Analysis of the manifestation of the flood of 20September 2020 and interpretation**

The hydrological modeling, showed that the interception of runoff was better in the two small western watersheds located in the immediate surroundings of the city, including wadi Shrarda and El Malih.

These watersheds have a slightly long shape, although the time of water concentration is less than 1 hour (54 min and 45 seconds) (Tab.1)

On the other hand, the streams that triggered the sudden and catastrophic floods come from the South and South-West sectors (basins 1, 2, 4 and 3) which have a very compact shape, especially for the El Ogla basin. But also because of the channeling of the Sayala wadi over 1.72 km and the lack of an adequate and well-designed urban sewage system (Photos. 1, 2 and 3).

Basin	Area	Perimeter	Kc	L	l	Drainage density	C.T
B1	3.53	7.934	1.18	3.66	1.29	3.21	35
B 2	6.624	12.09	1.31	4.60	1.46	5.95	84
B 3	1.943	5.894	1.18	1.950	0.997	4.63	39
B 4	3.317	8.484	1.30	2.758	1.097	5.62	38
B 5	8.807	15.827	1.49	6.574	1.340	3.1	81
B 6	6.841	13.3617	1.43	5.118	1.395	4.1	54 min
B7	3.637	10.268	1.50	4.265	0.849	3.16	53
Sayala	35.16	25.168	1.19	8.396	4.188	4.12	136 min

Table 1: The morphometric and hydrological parameters of the sub-basins

ISSN No:-2456-2165

Photos 1, 2 et 3: The flood effect in wadi Sayala

In addition, the urban expansion and engineering works have caused the diverting of the majority of intra-urban waterways. In fact, the volume of water that submerged the majority of the districts came, in large part, from the small intra-urban streams coming from the hills. This is all following the decrease in infiltration because of the inevitable extension of the urban fabric and the fact that concreted and compacted land does not absorb rainwater, in addition to the fact that the majority of the sewers of ONAS are clogged by overflow silt and clay debris. This is proven by the very high turbidity.

Indeed, the floods that occurred on 20/9 are of complex origin, a flash flood has caused an overflow of the majority of narrow streams that can no longer contain the excess water they receive from the hills of Amirat Hatim, Tyayra and Zarmedine.With the additional runoff from the Wadi El Ogla and its tributaries, huge amounts of water are rushing into the neighborhoods and houses located in saddle areas (Figs. 6.7.9).

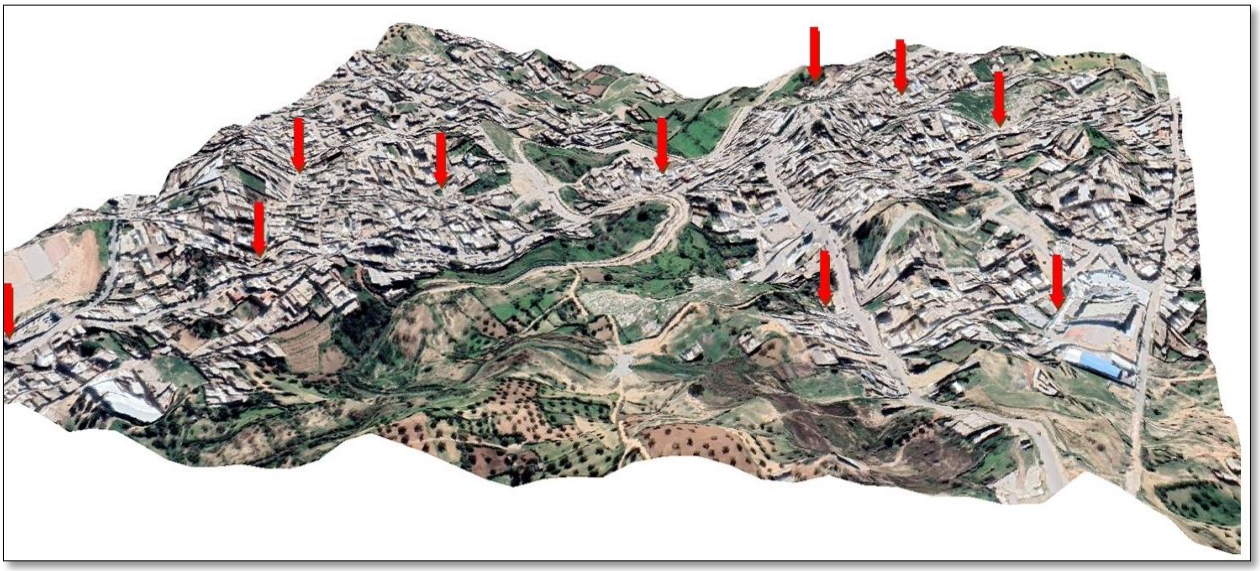

Fig. 6: Neighborhoods located in saddle areas constantly prone to submersion

ISSN No:-2456-2165

The most affected areas are El Flash, El wadi, El Ramadi and also the dwellings located on the north-eastern edges of the El Mandrea district. On the other hand, the districts that were sheltered from the floods of September 20, 2020, are Taoufik Mahjoub and those located between the ring road of Bni Hassen in the north and Tayeb El Mhiri Street in the southwest and it is thanks to their position perched on hills of 54 to 59 m. The abandoned extraction pits and those under use are generally rectangular, trapezoidal, triangular or oval in shape.

Their surface area varies from 1022 m² to 84338 m². They are arranged in a basin with a slightly regular bottom or in stepped basins separated from each other by a talus with a moderate and rectilinear slope crossed by tracks allowing the circulation of heavy vehicles and construction equipment. More than 70% of the excavations that have been in operation since the beginning of the second millennium are concentrated in the western part of the city of Bni Hassen of which 50% are located in the blue-green Miocene formation.

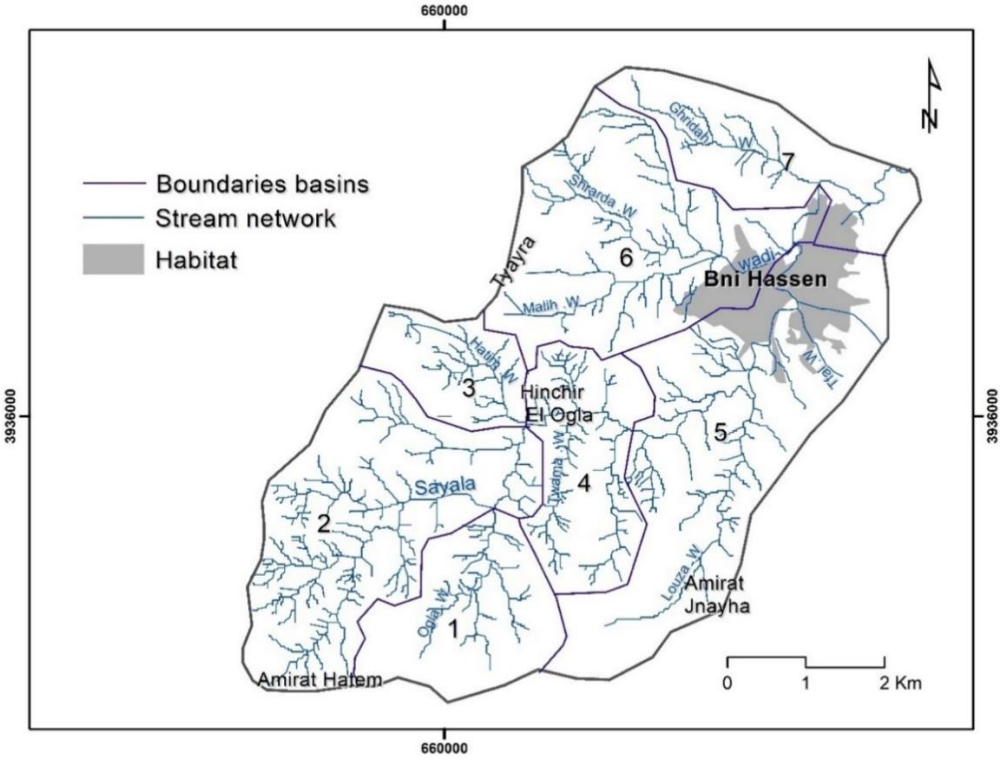

Fig. 7: Sub-basins of Sayala wadi (SRTM Image)

During the floods of September 20, 2020, runoff water first flooded the sub-catchment areas 1, 2, 3 and 4 because they are the least exploited from the point of view of extraction.

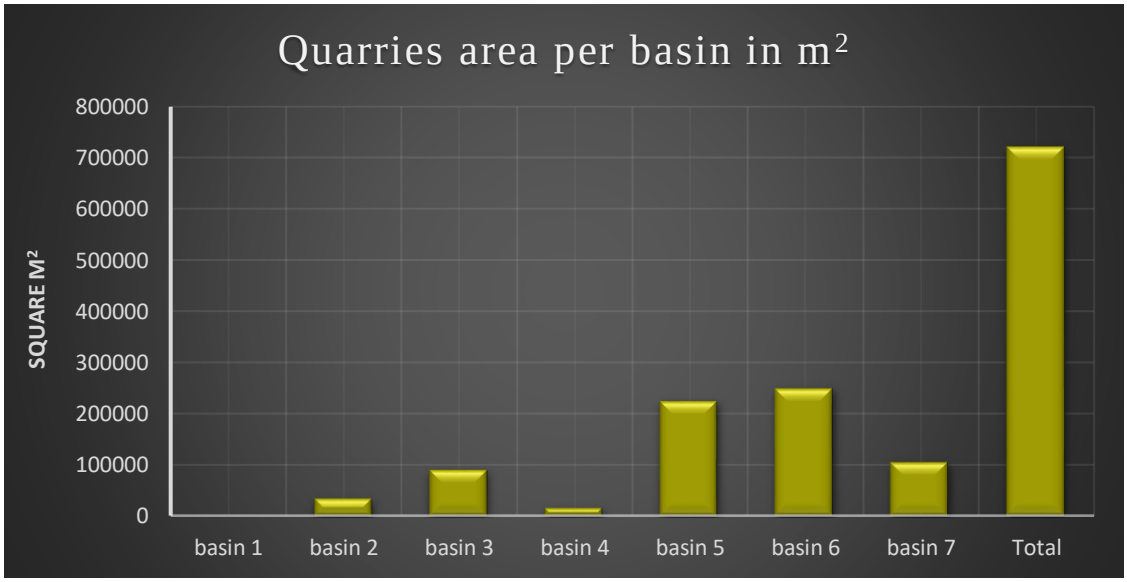

Fig. 8: Surface distribution of quarries by basin

ISSN No:-2456-2165

The number of pits that can hold water is smaller. This has allowed the water level to rise quite rapidly in these catchments. While the three catchments 5, 6 and 7 have experienced a slower rise in water level because they contain more than 80% of the total area of excavations (Fig. 8).

Thus, a considerable amount of runoff is retained either in extraction pits or impeded by mounds formed by excavation rubble and quarry discharge.

Currently, most of the excavations and abandoned quarries are transformed into ponds filled with water. They play the role of collecting basins of runoff water. Some areas are operated in small pits arranged in a contiguous manner, interconnected by drainage ditches that ensure the drainage of water during occasional rains. This is a solution to ensure the continuity of construction work that could be affected by the stagnation of water for a long period.

It should be noted, however, that the exploitation of clays in the region dates back to much earlier historical periods. This indicates an ancient practice and an early development of the Central Sahel region. This fact is proven by the existence of numerous excavations that have not been subject to recent mining, but the depth and presence of erosion talus, despite the low slopes, confirm that these areas seem to be ancient clay pits exploited in construction and the pottery craft industry.

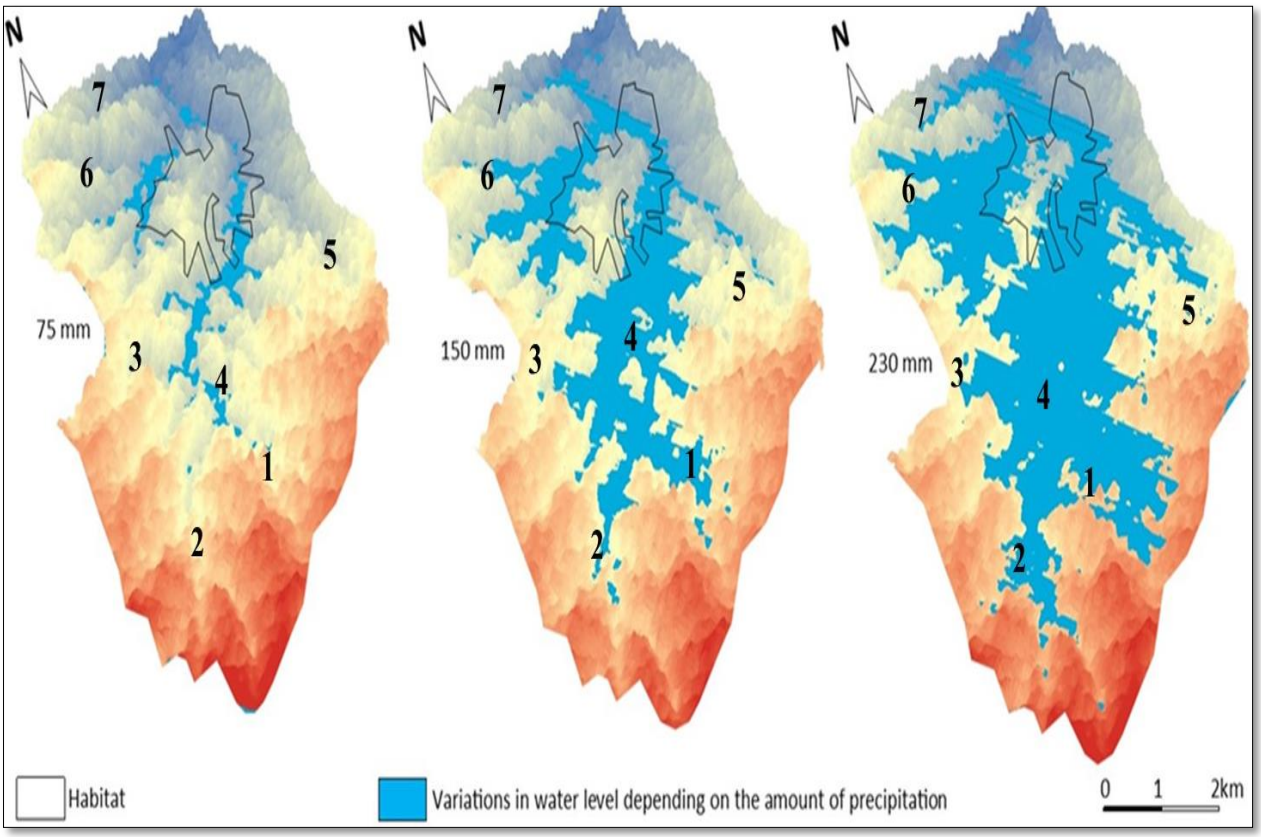

Fig. 9: Laminar sheet flow and submerged areas in Syala basin during a storm event of September 20, 2020

The latter has made the prosperity of old civilizations settled around the city of Moknine located 9 km from the city of Bni Hassen. The watershed of the Sayala wadi is home today to more than 23 km^2 of Roman centuriations and more than 13 km^2 are located around it. The network of these cadastres is oriented diagonally from South-East to North-West and extends in the same direction as the large centuriation of Chebba (Fig. 10).

Some clay pits have experienced an almost total filling following the strong erosive process that has taken two dimensions, natural and societal, especially after the unprecedented expansion of olive groves that currently represent more than 76.26% of the total area of the watershed (Fig. 11).

Also the old mode of mining is characterized by small pits of circular form having a very close arrangement to be able to fill the used-up pit by the waste of the new clay pit. This behavior and these peasant practices imply a good knowledge and an environmental awareness for a long time.

ISSN No:-2456-2165

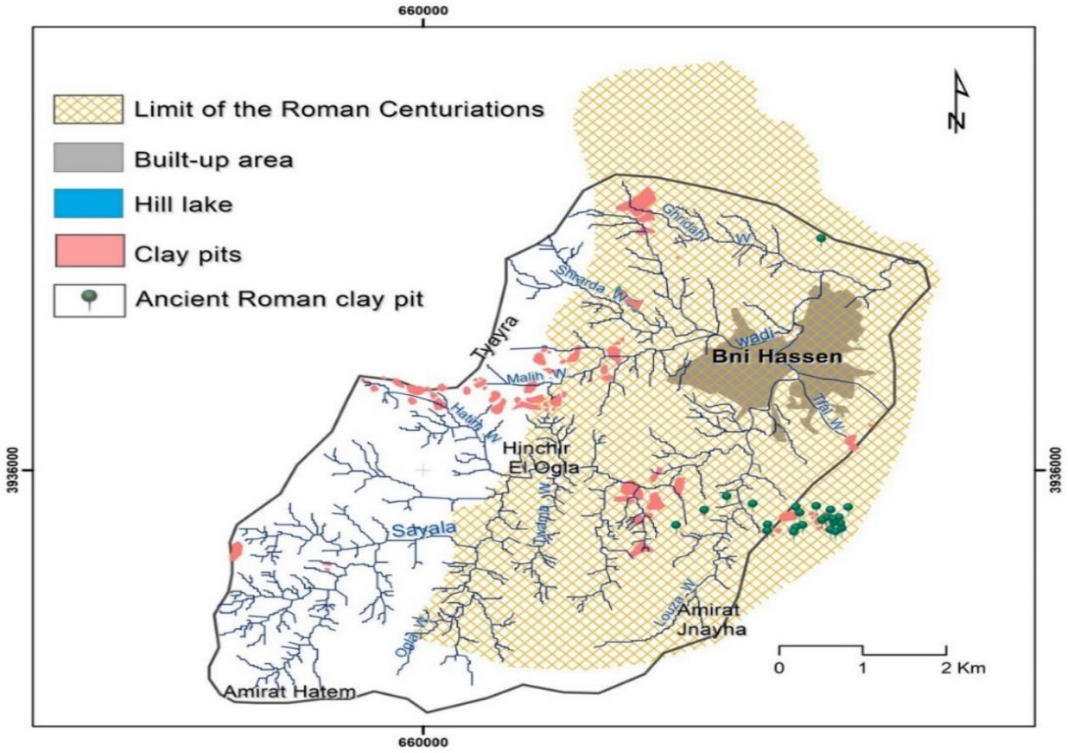

Fig. 10: Roman centuriation in the Sayala basin and its surroundings (Source: Atlas of the Roman Centuriations of Tunisia

However, it remains to be proven that this ancient mining activity by direct field investigation and by sedimentologic and pollen analysis in order to confirm the possible disturbances of the hydro system of the upstream course of the Sayala wadi and its tributaries, which had occurred several times.

Unfortunately, the initial reference equilibrium of the Central Sahel region is unknown. The definition of this reference state remains a step of crucial importance and it can only be done through sedimentologic and pollen analysis in the filling sediments in the old clay pits to better monitor the bioturbations and highlight the set of interacting factors that have shaped the ever-evolving ecosystems.

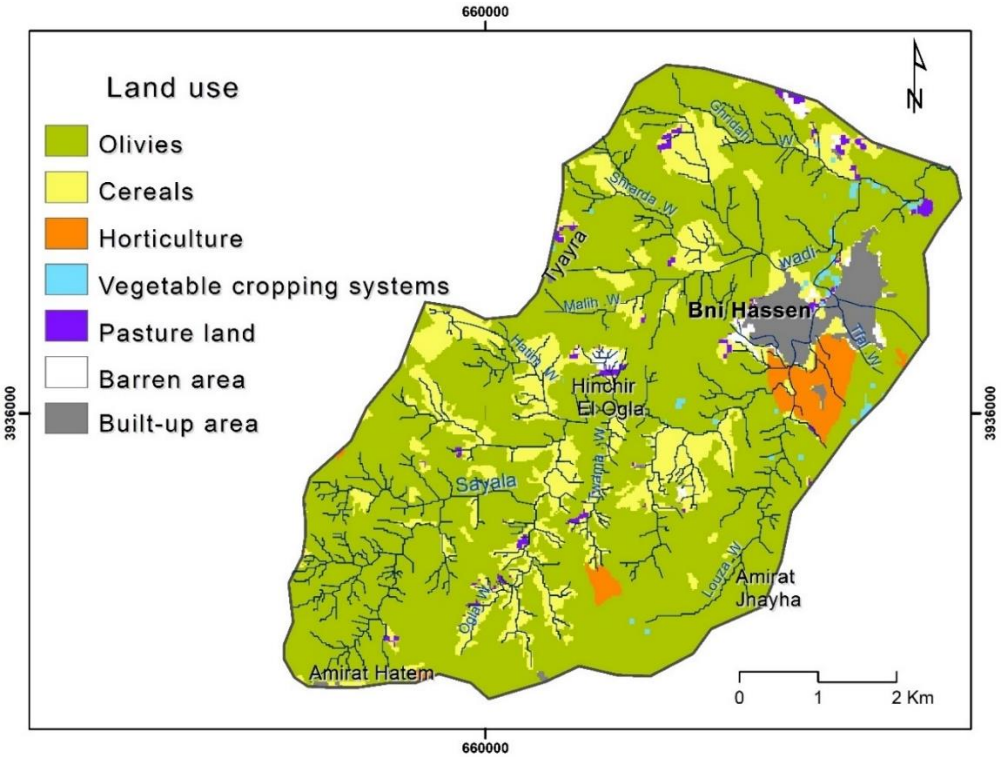

Fig. 11: Land use map of Sayala basin

ISSN No:-2456-2165

The region has experienced the activation of a considerable erosive potential because of the concentration of the flow near the city of Bni Hassen. An irreversible disturbance of the soil resources and biodiversity has occurred especially in the olive groves, where the waters are gaining more and more strength at the expense of the land located between the rows of olive trees. This is proven by the very high turbidity of the water that has flooded most of the houses in the districts of El Flash and the city of El wadi. The turbidity concerns the suspended solids in the runoff water. Measurements on three samples taken by some inhabitants show a turbidity that varies from 20g/l to 30g/l, which is considered high if we take into account the modest relief. It is certain that the low slopes are not able to generate high turbidity because the traction force of the flow is always low. Indeed, turbidity is linked to natural and human factors.

First, the mopho-lithological conditions, since almost the entire watershed is formed by plastic and loose rocks. Second, three other facts seem to be at the origin of the high turbidity. The autumnal flow which generally occurs on a cracked and fissured ground, which by gaining speed, causes the uprooting of soil particles. Then the modalities of the linear erosion and the erosion by very accentuated undermining of the riverbanks (Azaiez, Blelet al, 2021). Then the extraction activity, which is responsible for the release of weakly consolidated sediments. All these elements are of crucial importance in the increase of turbidity and the aggravation of the effects of floods. When these turbid waters frequently reach the city, they cause a clogging of the ONAS sewer system.

This situation is aggravated if local council workers do not empty the partially drowned accumulation areas. Thus, the huge decantation of silt and deposits can create counter-slopes and paralyze in the medium and long term the functioning of the special deflectors whose objective is to prevent any free flow of runoff water in the city districts. All these elements, each in its own way, have caused a rapid overflow of runoff water in the city of Bni Hassen which would be submerged by water in a few moments and completely paralyzed for several hours.

Indeed, the floods of September 5 and even those of 2016 could have been even more catastrophic in the absence of these clay pits. On its course, the speed of runoff water is significantly reduced thanks to the arrangement in steps of the excavations on the courses of wadi El Ogla coming from the south and wadi el Malih from the west. The small pits of extraction and the sectors of saddles located at 3km of the city of Bni Hassen play the role of basins of decantation of the sediments and the suspended matter and they served as retention basins.

Therefore, it is necessary to promote a management strategy that involves farmers and quarry owners in order to ensure rational exploitation and development of these abandoned excavations. Protection of the clay pits against rapid filling is essential. This protection can only be done through biological fixation of the channels and banks to slow down the transport of solids. This requires a real orientation of the rules and laws of mining, especially since the city of Bni Hassen is located on the borders of clay deposits of good industrial quality.

The open-air clay quarries are characteristic of the Central Sahel region. But it should be noted that the old clay pits and current quarries in the upstream part of the Sayala watershed have not been the subject of a landscaping and environmental study that aims directly at the effects of the quarries on the environment and especially on the behavior of the hydrosystem of the Sayala wadi. The field prospecting and the processing of high resolution SRTM images allowed us to make an inventory of the majority of the clay pits in order to propose a typology of these basins in terms of retention and infiltration capacity as well as in terms of their position in relation to the hydrographic network and the city of Bni Hassen (Fig. 12).

The results of this research can incite the local stakeholders towards a restitution and a rehabilitation of the abandoned excavated sites and to exploit the quarry discharges by using these sediments in other fields. These discharges come mainly from sand intercalation beds (Koeing et al, 2018; Sawatsky et al, 2018; José et al, 2020). It should be noted that these extraction pits have not been the subject of a very detailed stratigraphic study, except for a few researchers whose impact study was presented to the ANPE before the launch of the "Tejra" quarry between the region of Ghnanada and that of Beni Hassen.

ISSN No:-2456-2165

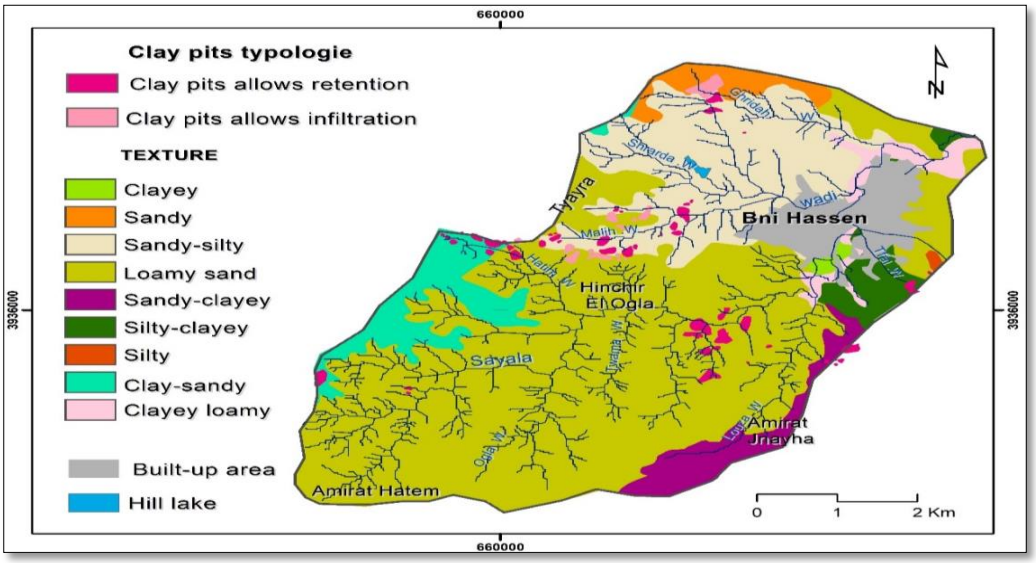

Fig. 12: Classification of extraction pits in terms of retention and infiltration according to soil texture

IV. RESULTS AND DISCUSSION

Currently, the majority of abandoned quarry pits that have not been restored are rapidly filling due to the instability of the slopes as a result of the combined effect of intense rainfall and irresponsible human behavior. Slide gullies, gullying, domestic waste, rubble and the discharge of non-exploitable sediments from the nearby quarries explain the rather rapid filling process of these retention basins (Fig.13).

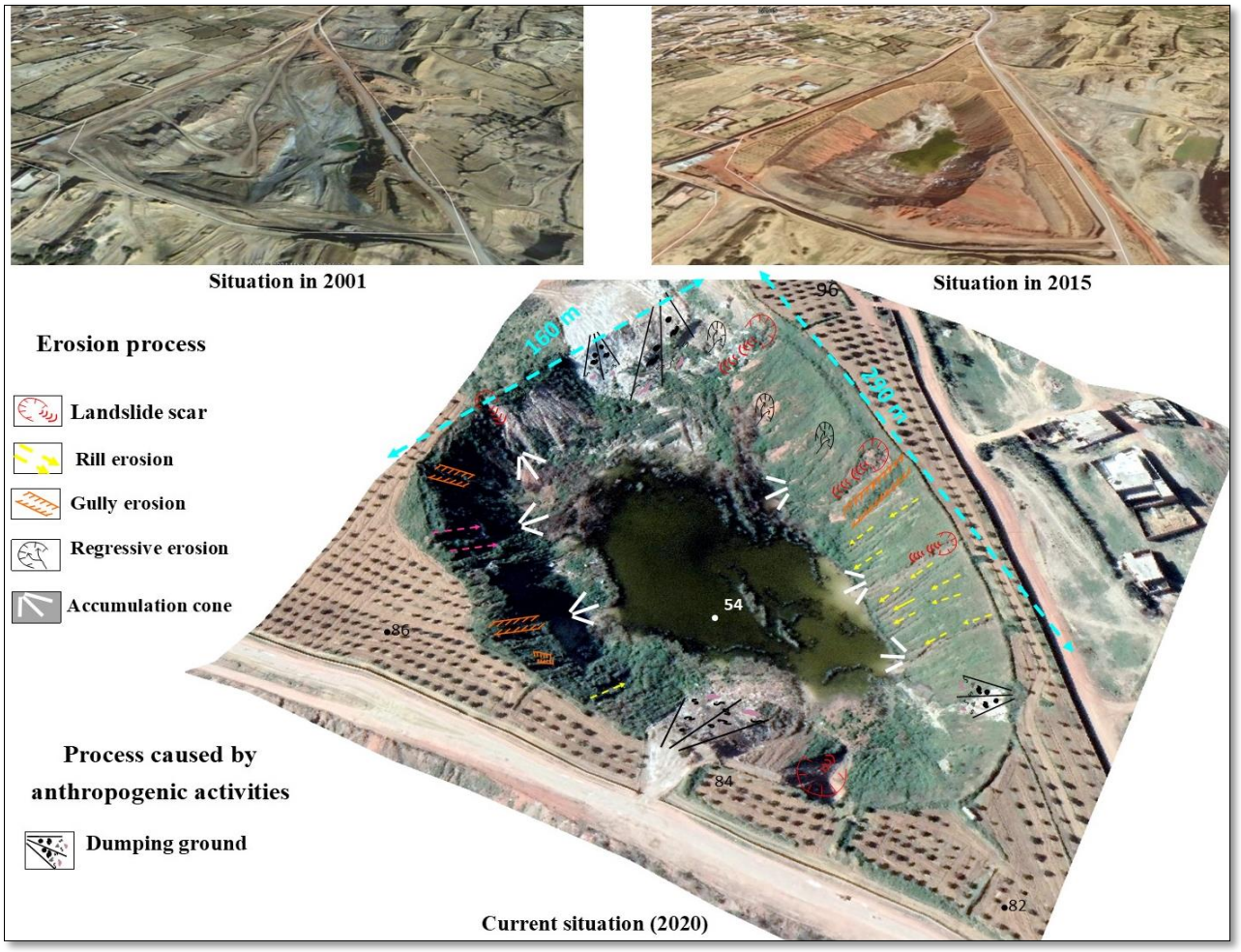

Fig. 13: An abandoned quarry runs the risk of filling (Images Google Earth Pro)

ISSN No:-2456-2165

The filling is also made by the decantation of clay minerals and by overflow silt coming from very turbid runoff water. The protection of the city of Bni Hassen against flooding must necessarily involve the understanding of the functioning of the hydrosystem during exceptional events, including the centennial floods that have marked the Mediterranean regions. This question must be examined according to two approaches: naturalistic and anthropocentric (Chenot, 2018, Azaiez et Ansar, 2021).

But it is important to think of a restoration that meets the concerns of the inhabitants, the state authorities, the users of the territory and the environment. An evaluation of the resulting effects is necessary at different times of the project, and it is necessary to think in terms of an evolving rehabilitation strategy in ord1er to produce a healthy landscape, shaped for man and by man (Chenot, 2018), especially since the area has been experiencing a regressive vegetation succession due to the deterioration of climatic conditions and human intervention during the last decades.

But we must not put everything on human responsibility, as many quarries have undergone a real rehabilitation and have been the subject of a restoration to equilibrium as close as possible to its initial state (Bradshaw, 1997; Koenig, 2018 José et al, 2020). A plantation of more than 225 olive trees was carried out in the extraction site located 1 km from the town of Tyayra. This restoration has given it a level of functionality in line with the state of the agricultural landscape around and away from the extraction areas (Fig. 14).

Multiple undulating ponds of water are formed at the expense of the abandoned quarries, frequently colonized by patches of exotic vegetation better adapted to humidity. Today, they contribute to improving the quality of the surrounding microclimate and are home to plant communities that replace rare steppe vegetation. This vegetation cover constitutes a boost for the agro-pastoral activity.

Fig. 14: Restored quarries, located on the western watershed between 2001- 2021(Images Google Earth Pro)

The city of Bni Hassen has been protected from more catastrophic flooding by the clay quarry pits that surround it in the shape of an arc on all sides. The floods of October 16, 2016 showed a good response from the excavations of clay quarries located upstream of the watershed of Wadi Sayala. The interception of runoff water is confirmed by a filling of almost all the pits, especially those located on the channel of Wadi El Ogla, El Malih and Shrarda (Fig. 18). The calculation of the volume of water that each pit can retain would not be an easy task, especially for quarries with an irregular bottom. It should be noted that the margin of error in depth is 1 m less. For this reason, two methods of calculation were chosen. The first one is applied to an SRTM image and on the basis of which the quarry polygons are draped. Through the two functions "Geometry zonal as table" and Surface Volume Tool», we managed to calculate the volume of quarry pits each separately and then the total volume which is about 2.69 million m^3 for all the pits located upstream of wadi Sayala and its tributaries. It is worth remembering that the total volume of runoff water obtained from the rational method was 15 million m^3. It should be noted that the convergence of all these rivers is in the center of the city of Bni Hassen. This volume of water is calculated only for the quarries that began operating in 2001 because Google Earth Pro images are not available before that time. Thus, old clay pits that date back to earlier periods have not been subjected to this calculation, despite the fact that their depth varies from 2 to 5 m and together cover an area of nearly 50 ha southeast of the city of Bni Hassen. The position of the quarry pits on the channels of the watercourses has reduced the power of runoff that was dissipated by drifting in the pits. These conditions probably spared the city from the arrival of additional water and consequently from more devastating floods (Fig. 15).

ISSN No:-2456-2165

Fig. 15: The damage caused by the 20/9/2020 flood in the city of Bni Hassen and its surroundings

A verification of these results will be necessary based on the total station records. Indeed, flood protection must be part of a continuous strategy that takes into consideration the annual, seasonal and daily rainfall variations. But also, according to the next extraction projects that are being implemented.

The watersheds most responsible for flooding in the city of Bni Hassen are 1 and 4. They have the shortest concentration time compared to the others (35 min and 38) and the most compacted shape (Kc = 1.18 and 1.30). The longitudinal slope of the streams is among the steepest. There is a correlation between the magnitude of flooding and the intensity of mining activity. This close relationship between mining activity and flood characteristics is verified by Principal Component Analysis. For catchment 3, the interception was good, despite its compact form and the short concentration time (39 min). This can be explained by the large number of mining pits and also by the fact that more than half of these pits have a high infiltration capacity, so that more runoff power is dissipated.

V. CONCLUSION

Coming to the end of the work, the results of this research have allowed to develop an idea of and share reflections on the relationship between flooding and extractive activity in the city of Bni Hassen and its surroundings. The majority of research done worldwide supports the view that insists on the negative causal effect between ecosystems that have taken a long time to maintain their equilibrium and the quarries that have profoundly altered the geomorphological landscape and agropastoral systems. The extraction activities could have provoked more serious floods if the slopes were steeper upstream, because the waters arrived in the city in flush, even in the presence of the extraction pits, because the excavations arranged in steps on an inclined plane would be only half filled. Thus,

the unavoidable urban sprawl and the acceleration of the exploitation of clay mineral resources must be taken seriously in the region of Bni Hassen. The strategy of rehabilitation and planning must be designed while taking into account the extreme rainfall events. It is necessary to startwith the establishment of preliminary multidisciplinary reflections in order to take maximum advantage of these quarries as water storage units. This will allow the gradual return of water, especially in the agricultural field. This way, resilience is strengthened and the ecosystem acquires more capacity and skills to absorb disturbances, especially for areas that are under the threat of potentially recurrent flooding.

ACKNOWLEDGEMENTS

The authors want to extend their appreciation and their gratitude to the Deanship of Scientific Research at King Khalid University Saudi Arabia for providing administrative and technical support and for funding this work through General Research Project under grant number (GRP/228/43).

- **Funding:** The authors are funded through the General Research Project from the Deanship of Scientific Research at King Khalid University under research grant number (GRP/228/43)

REFERENCES

[1.] Abdelkhalek Abderrahmen, 2009, Les intensités des pluies dans la Tunisie orientale, Thèse de Doctorat en climatologie, Université de Tunis Faculté des Sciences Humaines et Sociales Département de Géographie, 315p.

[2.] Ansar, A et Azaiez, N. 2022,Mapping of flood zones in urban areas through a hydro-climatic approach: the case of the city of Abha, Earth Science Researchjournal, DOI:10.5539/esr.v10n2p1

[3.] Azaiez, N. Ansar, A. 2022,Le risque d'inondation dans le quartier d'El Mensek: de l'aléa morpho-hydro-météorologique au risque résiduel d'ordre socio-naturel (Abha, Arabie Saoudite), Algerian Journal of Engineering Architecture and Urbanism Vol. 6 Nr. 4 2021 ISSN: 2588-1760, https://www.aneau.org/ajeau/

[4.] Azaiez, N., Baazaoui, N., Blel, I.F. *et al.* 2021. Contribution of the adjusted empirical analysis of the RSULE and FAO models in the estimation of soil losses in the watershed of Wadi El Hayat (Saudi Arabia). *Arab J Geosci* 14, 2185 (2021). https://doi.org/10.1007/s12517-021-08561-7

[5.] Azaiez. N., 2016, La dynamique géomorphologique actuelle dans le bassin versant de l'oued el Meleh Bou el Ajraf (Tunisie Centre orientale) : Cartographie et essai de quantification de l'érosion hydrique. Thèse de Doctorat, Université de Tunis I, 271 p.

[6.] **Ben Salem. A, Majdoub. R, Y et Khlifi. S, 2013,**Importance of the Meskat system and its landscape insertion through the olive groves of Sousse Region (Tunisian Sahel), International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 4 No. 2 Oct. 2013, pp. 396-400 Innovative Space of Scientific Research Journals http://www.issr-journals.org/ijias/

Bradshaw, A., 1997, Restoration of mined lands—using natural processes. Ecol. Eng. 8, 255–269.

[7.] Chenot .J, 2018, Réhabilitation écologique d'écosystèmes dégradés par l'exploitation des carrières : faire avec, refaire ou laisser faire la nature ? Biologie végétale. Université d'Avignon, 2018. Français. ffNNT : 2018AVIG0344ff. fftel-02070639.

[8.] José F, Martin Duque. Maria Tejedor, Cristina Martin Moreno, José M. Nicolau, Sanz Santos, Miguel. A, Ramon Sanchez Donoso and José M. Gomez Diaz, 2020, Geomorphic landscape design integrated with progressive mine restoration in clay quarries of Catalonia, International Journal Of Mining, Reclamation and environment, p 24, https://doi.org/10.1080/17480930.2020.1844368

[9.] Hooke R.L., Martín Duque J.F., and Pedraza.J., 2012, Land transformation by humans, GSA Today 22 (12) (2012), pp. 4–10. doi:10.1130/GSAT151A.1

[10.] Sawatsky. L and Beersing .A, 2014, Configuring mine disturbed landforms for long-term sustainability, Proceedings of Mine Closure Solutions, 2014, April 26-30, Minas Gerais, Ouro Preto.

[11.] Zarrad. B,**Majdoub. R, Y et Khlifi. S, 2010,** Impact du système meskat sur certains indicateurs physiques du sol, Actes des 17èmes Journées Scientifiques sur les Résultats des Recherches Agricoles 16 et 17 décembre. 2010, pp 984-993.

[12.] Kirpich Z., 1940, Time of concentration of small agricultural watersheds. Civil Engineering, 10(6):362

[13.] Koenig M.P, 2018, L'argilière d'une tuilerie antique, Archéopages DOI : https://doi.org/10.4000/archeopages, p 11.

[14.] **Lachaal .F, Mlayah .A, Anane .Met Leduc .CH, 2013,** Comprehension and hydrogeological conceptualization of aquifer in arid and semi-arid regions using integrated hydrogeological information system: Case of the deep aquifer of Zéramdine-Béni Hassen (east-central Tunisia), Arab J Geosci (2013) 6:2655–2671, DOI: 10.1007/s12517-011-0498-x