Mitigation of fugitive dust impact arising from BR dry disposal

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Abstract: The development of international policies about environmental defense has enforced some major modifications in the management of industrial tailings. As regards the disposal of the residue deriving from the bauxite processing (BR) in the alumina industry, national and international regulations have encouraged the evolution from wet to dry disposal techniques. However, such a change in the storage practices poses a major concern due to the potential increase of the atmospheric impact in the surrounding areas, due to the emissions of Particulate Matter (PM) generated both by the BR disposal activities and by the wind erosion over the dried surfaces of the landfill. The article analyses the effect of the impact mitigation measures typically adopted to control PM emissions with reference to a major red mud basin located in the southwest of Sardinia (Italy). The PM dispersion models performed with the CALPUFF code (US EPA) allowed, for the case study under consideration, the estimate of the improvement provided by moistening the dry surfaces and reducing the total length travelled par year by the machinery involved in material handling, transportation and disposal.

Keywords: bauxite residue (BR), particulate matter (PM), fugitive dust, dust air dispersion, atmospheric impact, air pollutants.

1. Introduction

Before the seventies only seawater discharge and lagooning were in use worldwide for the disposal of the residue deriving from the Bayer process (purification of aluminum hydroxide) for the production of alumina (aluminum hydroxide). In fact, until that time the alumina industry, the governmental authorities and the human communities did not consider the bauxite treatment and the residue disposal as a critical issue.

From the seventies, the rapid growth of the alumina industry, the evolution of the environmental protection regulation and the ever-increasing social awareness about environmental impact issues have enforced the adoption of dry storage practices, such as dry stacking and dry disposal, aimed at reducing the environment impact on soil and groundwater. Nowadays 30% of the alumina refineries worldwide practice lagooning and marine discharge, while the remaining 70% have converted their practice into dry disposal [1].

However, such a change in the storage practice has posed a major concern with respect to the potential increase of fugitive dust impact, due to the work activities involving material moving and placing within the basin and to the wind erosion over the dried surfaces, both during the basin operation and afterwards, in the post-closure stage.

The article analyses the effect of the impact mitigation measures typically adopted to control fugitive dust emissions with reference to a major BR (Bauxite Residue) basin located in the southwest of Sardinia (Italy). It is worth mentioning that the same case study has been taken into consideration in previous articles [1, 2, 3]. The present paper includes and discusses the results of the PM impact analysis associated with the latest revision of the basin conversion project, according to the indications given by the governmental authority in the frame of the ongoing *Environmental Impact Assessment* (EIA) procedure [4, 5].

2. Bauxite residue storage practices

2.1. Marine discharge and lagooning

Marine discharge consists in the direct disposal of the residue into the ocean, by means of a pipeline that releases the slurry offshore. Nowadays, only a small percentage of red mud is disposed into the sea (around 2 – 3%).

The lagooning method consists in pumping a residue with a 25 – 30% solid content into ponds formed within natural depressions or into constructed basins. Ponds are usually lined to minimize underground liquor leakage. The reliability of the seal increases with the reduction of the hydrostatic pressure inside the basin, attainable by removing the liquor or draining the deposit. In such basins the liquor content is reduced to 35 – 30% either by evaporation from the lagoon surface and because of the mud consolidation process.

The potential environmental risk due to BR disposal is related to the physical and chemical properties of the residue, which essentially depend on the type of raw material in use (bauxite), on the processing parameters and on the residue treatment before disposal. When considering the potential impact on the soil and the aquifer, the key points to be taken into consideration are the residue water content, the water pH and the potential capacity of the solid particles to release alkaline ions into rainwaters [2].

Because marine discharge implies direct contact between the residue and the seawater, it represents the disposal practice with the highest environmental risk. Whereas the potential environmental hazard posed by land disposal depends on the amount and quality of fluid in the mud and by the effectiveness of the geological barrier (natural or artificial) in sealing the deposit and avoiding the contaminant migration into soil and groundwater. In that sense, lagooning certainly represents the most precarious option among land disposal practices [2].

2.2. Dry stacking and dry disposal

Dry stacking requires the residue to be thickened before discharge, until a solid content between 48-55% is reached. Within that range, the mud is thixotropic and can be pumped and transported by means of suitable conduits.

After discharging, the residue descends along a slope with a resting angle between 2° and 6°. The discharged layers are left to drain and dry in the air before overlaying the next stratum. This way the mud consolidates to a solid content of about 62-65%, while the liquid phase is removed because of surface decantation and evaporation.

The dry mud is self-supporting and the deposit can be developed to reach significant heights without the need for containment structures and, therefore, with a significant reduction in the construction and maintenance costs. In relation to the relatively low residual water content in the mud, dry stacking provides some significant results in terms of soil occupancy and contamination risk, as it minimizes the use of land and the potential for leakage. On the other hand, it requires a further level of treatment before discharge (thickening or filtration) and additional technical measures to control dust emission from the deposit surfaces.

Dry disposal requires the process residue to be filtered to a solid content of about 65-70% and washed with water or steam to recover the soda and reduce the alkalinity. The dry mud is transported to the disposal area by trucks or conveyors. This method improves the positive attributes already mentioned for dry stacking, as it requires even smaller extent of land and no containment structure, and avoids the environmental and health hazards associated with the presence of open caustic lakes, whereas the potential for leakage to the ground and groundwater is minimised. On the other hand, it requires the installation of large filtration plants and washing devices, as well as the implementation of specific technical measures to mitigate the dust lifting from the deposit surfaces.

3. The case study

The red mud basin under consideration is located in the southwestern cost of Sardinia (Italy), within the industrial area of Portovesme (Figure 1). Since the seventies, the bauxite residue has been disposed by the lagoon method.

Considering the geographic location of the basin and its relative meteorological variables (rain and evaporation rate), the prospect of adding new embankments over the existing basin would imply a constraint on the vertical growth rate of the basin up to a limit of 1 m/y.

In fact, only by slowing the basin vertical development, the red mud already disposed in the basin would reach by consolidation the required solid content (about 65%).

Figure 1. BR basin of Portovesme (Italy)

The currently available evaporation surface (84.8 ha) combined with the limit in the raise velocity (1 m/s) would consent a maximum discharge volume of 850,000 m^3/year, corresponding to a maximum production of alumina of 1,580,000 t/y [3]. In four years time the total evaporation area would be reduced to 66,4 ha, the maximum dischargeable volume would be 664.000 m^3 and the alumina production rate could not exceed 1.230.000 t/a, with potential adverse effects for the alumina company in terms of economic outcomes.

From this perspective, also considering the unavailability of land and the environmental impacts associated with the hypothesis of a new basin in a different site, a conversion project has been developed to change the disposal practices from dry lagooning into dry disposal and use the existing basin [3].

3.1. The basin conversion project

Since a few year ago the red mud has been disposed in the three existing sectors of the basin A, B and C, represented in Figure 2. The two main sectors A and B are 26 m high and cover 114 ha of land; they have been developed according to the up-stream method and presently consist of a 10 m high lower embankment and 9 secondary embankments. Sector C is composed of a base embankment and only one secondary embankment, it covers 44 ha of land and is 11,5 m high.

The basin conversion project includes a variety of preliminary operations necessary to adapt the existing three sectors of the basin to the requirements of the EU Directive *on the landfill of waste* [6] and prepare an additional disposal area towards the north for the enlargement of the basin (new sector D). Figure 3 represents the future intermediate configuration of the basin (+18.5 m slm), with the three existing sectors (A, B and C) and the new sector D.

The modification of the disposal practice from lagooning to dry disposal also implies the construction of a filtration plant to allow the dehydration of the bauxite residue to a solid content of about 70%. Once dried, the residue is loaded onto the dump trucks and transferred to the basin summit, where is discharged into few main piles from where is reloaded, spread and rolled by means of traditional earth-moving machinery (wheeled loaders, dozers, compactor rollers).

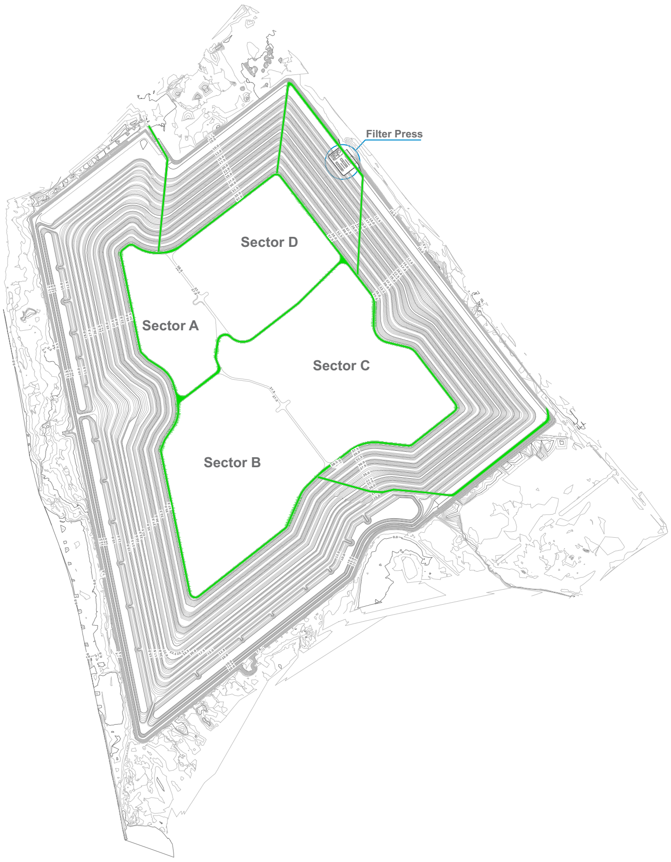

Figure 2. Basin configuration (+18.5 m slm)

The conversion of the disposal practice brings together the company's economic interest and a lesser overall impact on the environment, both during the production process and in the post-closure phase. As regards the operation of the landfill, in particular, the disposal of a dried residue will overcome the limit enforced by the consolidation velocity of a wet residue, as it eliminates the association between the annual outcome of alumina and the extent of the evaporation surface. Furthermore, the disposal of a dried residue eliminates the need to build additional upper embankments, this resulting in a consistent reduction of the construction costs. From the environmental point of view, the removal of a greater amount of liquor prior to disposal decreases the potential danger for soil and the aquifer contamination, which only remains dependent on the liquid content in the wet mud already disposed by lagooning. On the other hand, the conversion project requires the modification of the basin characteristics to allow the implementation of the new disposal procedures (loading, transport and location of the dried residue), which also implies the formation of new large dried surfaces exposed to wind erosion, with consequent increase of fugitive dust emission. In order to reduce dust emission at the source, the following technical measure have been included in the conversion project under consideration: moistening or chemical treatment of dry surfaces, revision of work organization and wind barriers.

As regards the wind barrier, in particular, an experimental research is presently in progress to estimate the threshold velocity that activates the dust-lifting phenomenon. That implies the use of specific instrumentation, equipped with a laser scattering system for the real time detection of air dust concentration (TSP, PM10 and PM2,5). The simultaneous measurement of the wind velocity and direction near the basin surfaces exposed to wind, at few centimeters from the ground, will be necessary to correlate the threshold velocity to the liftinf phenomenon. The results of the research will permit the design of a barrier system calibrated for the case study under consideration.

In the following part of the article, the results of the dust dispersion simulation are reported with reference to the effect provided by revising the work organization and moistening the dry surfaces of the basin, with mobile or fixed equipment. The first point, in particular, implies the reduction of the number of earth-moving machinery to be used for material disposal, according to the new storage practise.

4. The PM dispersion modelling

4.1. The CALPUFF code

The dust dispersion simulation has been carried out with the CALPUFF model system, developed by Sigma Research Corporation (currently part of Earth Tech, Inc.), with the contribution of the California Air Resources Board [7]. The modelling domain for the case study under consideration is a square with sides of 20 km, centered in the red mud basin (within the Industrial Area of Portovesme), and includes the two nearest villages of Paringianu and Portoscuso, respectively at 800 m and 3 km, which represents the main receptors in the surrounding territory.

4.2. Characterization of fugitive dust sources

Tables 1 reports all fugitive dust emission sources (from S1 to S8) included in the lasted revision of the basin conversion project (construction activities, disposal operations and wind erosion) and the applicable EPA AP42 codes [8]. For each of the eight sources under exam, Table 2 indicates the specific algorithm for the valuation of the PM10 Emission Factors (PM10 EF), as well as the equation parameters needed for the calculation. Table 3 reports the operating parameters used to calculate the Emission values (E): input data of the impact prevision models. For the activity S3 (Dry mud), two cases were considered: Case A (dumper capacity of 16.3 m^3 and Case B (dumper capacity of 20.0 m^3).

Table 1 – Fugitive dust sources and selected EPA AP42 codes

Code	Fugitive dust source	EPA AP42
S1	Dry mud unloading from filter press	11.19.2 Conveyor Transfer Point
S2	Dry mud loading into truck	11.19.2 Truck
S3*	Material transport with dumpers	13.2.2 Unpaved road
S4	Heap formation & material handling with loaders	13.2.4 Aggregate Handling and Storage Piles
S5	Stockpile handling	13.2.5 Industrial wind erosion
S6	Material placing with motor graders	13.2.3 Heavy Construction Operations - Grading equation Tables 11.9-2
S7	Material rolling with dozers	13.2.3 Heavy Construction Operations- Dozer equation in Tables 11.9-2
S8	Wind erosion from exposed surface	SPPC 1983 - Appendix A Section 1.1.17 to 1.1.18

*Includes: Dry mud, bottom and fly ash, lateral capping building materials

Table 2 – PM10 Emission Factors (EF)

Code	EF $_{PM10}$	Equation parameters
S1	5.50 10^{-4} [kg/Mg]	
S2	5.50 10^{-4} [kg/Mg]	
S3*	$k \cdot \left(\frac{s}{12}\right)^a \cdot \left(\frac{W}{3}\right)^b \cdot 291.8$ [kg/km]	k, a, b = particle size coefficient s = surface material silt content (%) W = mean vehicle weight (tons)
S4	$k \cdot 0{,}0058 \cdot \frac{1}{M^{1{,}4}}$ [kg/Mg]	k = particle size multiplier U = mean wind speed (m/s) M = moisture content (%)
S5	7.9 10^{-5} *a movh* [kg/h]	*a* = area of moved surface (m^2) movh = number of movements per hour (1/h)
S6	$0.0056 \cdot 0{,}6 \cdot (S)^{2.0}$ [kg/km]	S: mean vehicle speed (km/h)
S7	$\frac{0{,}45 \cdot (s)^{1{,}5}}{(M)^{1{,}4}} \cdot 0{,}75$ [kg/h]	s: silt content (%) M: moisture content (%)
S8	0.2 [kg/ha/h]	

*Includes: Dry mud, bottom and fly ash, lateral capping building materials

Table 3 – Estimate of Emission (E): operating parameters

Code	Operating parameters
S3 (Dry mud) *Case A*	a = 0.9 b= 0.45 k= 1.5 s = 10% W = 55 tons Diurnal kilometer travelled: 556 km Nocturnal kilometer traveled: 181 km
S3 (Dry mud) *Case B*	4.0 cm a = 0.9 b= 0.45 k= 1.5 s = 10% W = 59 tons Diurnal kilometer traveled: 453 km Nocturnal kilometer traveled: 147 km
S3 (Bottom and fly ash)	a = 0.9 b= 0.45 k= 1.5 s = 10% W = 40 tons Daily kilometer traveled: 37.5 km
S3 (Lateral capping building materials)	a = 0.9 b= 0.45 k= 1.5 s = 10% W = 55 tons Daily kilometer traveled: 77.5 km
S8	S =65 ha

The Emission values (E) in Table 4, used to run the air dispersion models, refer to the two scenarios: Scenario 1 (emission without mitigation) and Scenario 2 (emission with mitigation). Scenario 2 represents, in fact, the additional effect provided by wetting the basin surfaces: unpaved roads, top and lateral surfaces of the basin. An abatement efficiency of 85% has been assumed to run the simulation of Scenario 2.

Table 4 – Emission values (E) for the two modelling scenarios

Code	***Scenario 1*** kg/h	***Scenario 2*** kg/h	notes
S3 (Dry mud) *Case A - DAY*	46.15	6.92	16 /24 h 7/7 day per week
S3 (Dry mud) *Case A - NIGHT*	30.05	4.51	8 /24 h 7/7 day per week
S3 (Dry mud) *Case B - DAY*	38.82	5.82	16 /24 h 7/7 day per week
S3 (Dry mud) *Case B- NIGHT*	25.25	3.79	8 /24 h 7/7 day per week
S3 (Bottom and fly ash)	3.57	0.54	12 /24 h 5/7 day per week
S3 (Lateral capping building materials)	12.87	1.93	8 /24 h 5/7 day per week
S8	13	1.95	Wind velocity > 3.09 m/s

5. Results and discussion

As mentioned above, the prevision models of dust dispersion were performed with reference to two hypothesis of work organization (Case A and Case B) and two Scenarios (Scenario 1 and Scenario 2). The modelling results refer to the following configurations:

1. Case A – Scenario 1
2. Case B – Scenario 1
3. Case A – Scenario 2
4. Case B – Scenario 2

For each configuration, the results are reported in a numerical format for the four points (CENPS 2, CENPS 4, CENPS 6 and CENPS 7) corresponding to the locations of sampling stations set up by the Environmental Protection Agency of Sardinia (ARPAS) [9] shown in Figure 3.

The incremental impact of the basin to the PM concentration values recorded by the ARPAS monitoring system allows the comparison with the limit values established by Directive 2008/50/*EC on ambient air quality and cleaner air in Europe* [10]. It is worth mentioning that the Directive establishes the limit values of PM10 for one day (50 μg/m^3, not to be exceeded more than 35 times a calendar year) and for a calendar year (40 μg/m^3); both limits have been in force since January 2005.

For each of the four simulated configurations, the contribution of the red mud basin resulting from the prevision models is given in terms of dust concentration for the 36th worst day (mean daily value) and mean annual value. Only for the first and last configuration (1 and 4) the results are reported also graphically (iso-concentration maps).

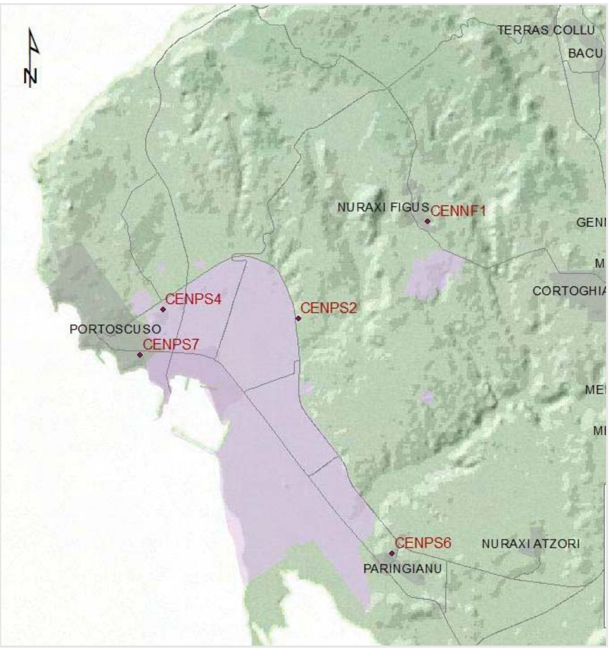

Figure 3. ARPAS air quality monitoring system

5.1. Simulation numerical results

Table 5 and Table 6 report the numerical results of the simulations for the configurations under exam. As shown in Figure 3, the sampling stations CENPS6 and CENPS7 represent respectively Paringianu and Portoscuso, the two villages nearest to the impact source.

The PM10 concentration values in Tables 5 and 6 refer to the 36th worst day of the year (mean daily value) and to the mean yearly value (Y). All the simulated concentration values are far below the limits established by Directive 2008/50/*EC*, yet they solely represents the contribution of the red mud basin, while the impact evaluation procedure (i.e.: confrontation with the limit values) requires the additional contribution of the PM10 concentration registered at the sampling stations.

The significant difference between the concentration values at the North side of the BR basin (Portoscuso) and those at the South (paringianu) depends of the Sardinian prevailing wind from North-West (*maestrale*).

Table 5 – PM10 concentration at the sampling stations

	Case A			
	Scenario 1 [mg/m^3]		***Scenario 2*** [mg/m^3]	
	36th day	Y	*36th day*	Y
CENPS2	2,57	0,71	0,39	0,11
CENPS4	2,91	0,84	0,44	0,13
CENPS6	8,70	3,02	1,31	0,45
CENPS7	3,65	1,16	0,55	0,17

Table 6 – PM10 concentration at the sampling stations

	Case B			
	Scenario 1 [mg/m^3]		***Scenario 2*** [mg/m^3]	
	36th day	Y	*36th day*	Y
CENPS2	2,20	0,61	0,33	0,09
CENPS4	2,47	0,72	0,37	0,11
CENPS6	7,32	2,58	1,10	0,39
CENPS7	3,17	0,99	0,48	0,15

As regards the confrontation between Scenario 1 and Scenario 2, the reduction in terms of air dust concentration is necessarily correspondent to the moistening abatement efficiency assumed as input data (85%). While the mitigation offered by using dumpers of greater capacity is in the range between 13 and 16%, when considering the daily mean values, and around 15% when considering the annual mean values.

The global reduction of PM10 concentration at the receptors given by both moistening the dry surfaces and reducing the number of earth-moving vehicles involved in the construction and disposal activities is around 87 %.

5.2. Simulation Graphical results

Figures from 4 to 7 represent the resulting isoconcentration curves for the worst (Case A – Scenario 1) and the best case (Case B – Scenario 2) under consideration.

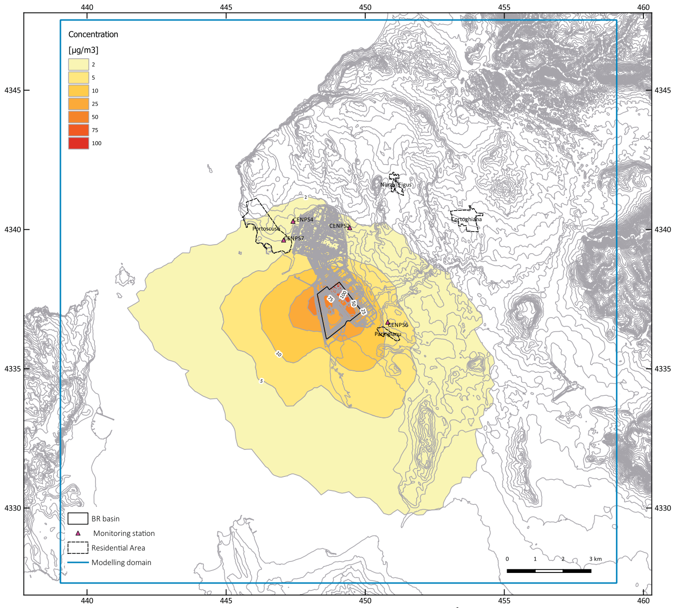

Figure 4: Case A - Scenario 1 (36th worst day)

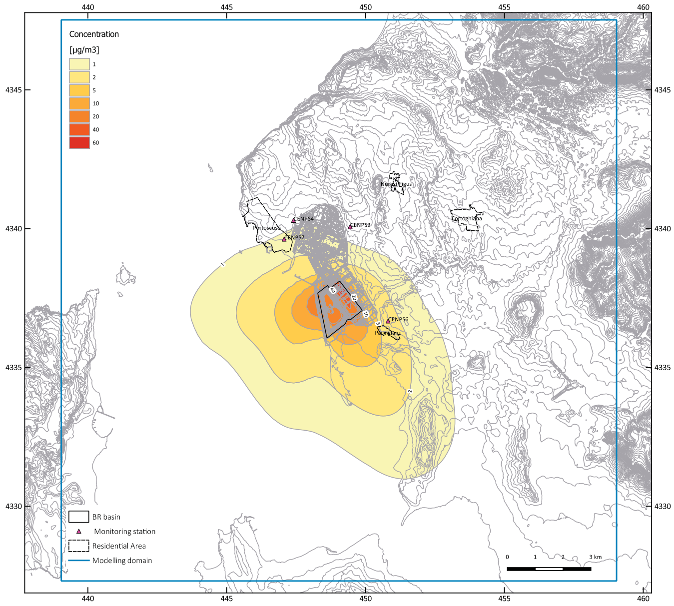

Figure 5: Case A - Scenario 1 (annual mean)

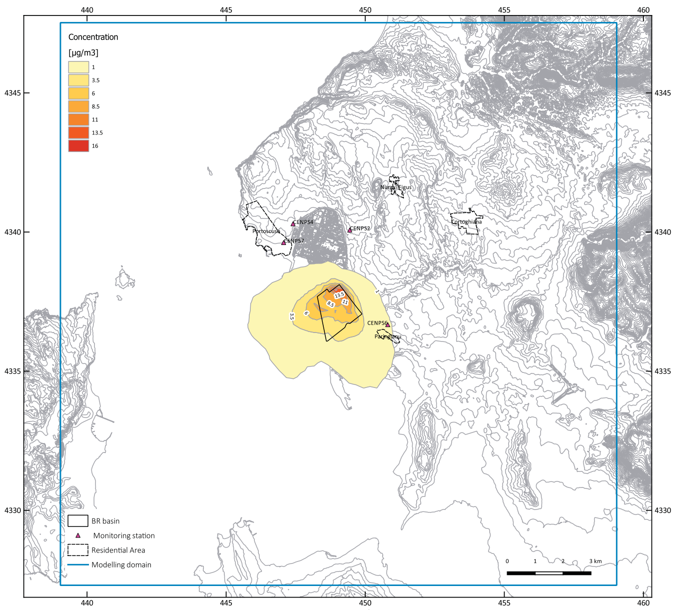

Figure 6: Case B - Scenario 2 (36th worst day)

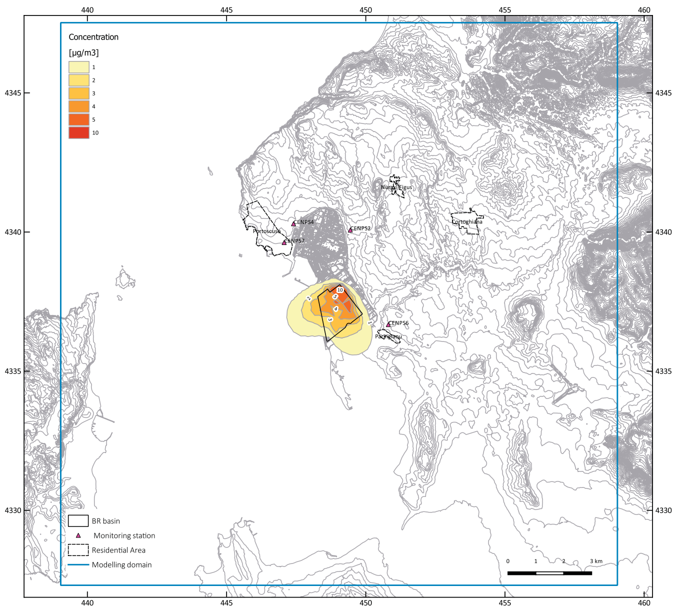

Figure 7: Case B - Scenario 2 (annual mean)

1. Conclusions

The recent change in the red mud storage practices has posed a major concern due to the potential increase of PM atmospheric impact due to the disposal activities and the wind erosion. The article analyses the effect of the impact mitigation measures to control PM emissions with reference to a major red mud basin located in the southwest of Sardinia (Italy).

The PM dispersion models performed with the CALPUFF code (US EPA) allowed the estimation of the improvement provided by moistening the dry surfaces and by reducing the total length travelled par year by the machinery involved in the construction and disposal activities. The results showed that the global reduction of PM10 concentration at the nearest receptors (Paringianu and Portoscuso) is around 87%.

Apart from the potential improvement provided by the reduction of the total length travelled par year (i.e.: use of bigger machinery) and by moistening the dried surfaces, an additional mitigation measure is represented by the erection of wind barriers. In fact, an experimental research is presently in progress to estimate the threshold velocity that activates the dust-lifting phenomenon. That implies the use of specific instrumentation, equipped with a laser scattering system for the real time detection of air dust concentration (TSP, PM10 and PM2,5) and the simultaneous measurement of the wind velocity and direction near the basin surfaces exposed to wind, to correlate the threshold velocity to the lifting phenomenon. The results of that research will permit the design of a barrier system calibrated for the case study under consideration, which will be the object of a future article.

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