GENERAL SUMMARY AND CONCLUSION

The agro-based industries in the cooperative sector hold an important position in governing the economy, education, politics and social activities not only in the Maharashtra but in the country, for the rural population and have been able to change the face of rural area within their territory. Presently, there are 1750 agro-based industries in the country, out of which 553 contribute a lion's share as sugar industries. Maharashtra is one of the leading states having 189 sugar industries owned by private and cooperative sectors. In spite of the fact that the agro-based industries are the backbone of rural economy of rural Maharashtra; subsequently a need has been arisen to review and take cognizance of other associated environmental problems with it. The enormous quantities of waste generated and released by these rural industries in many parts of the state created the problems of water, air and soil pollution.

The agro-based industry i.e. Vasantrao Dada Patil Sahakari Sakhar Karkhana at Vithewadi started crushing in 1984 with a capacity of 1250 ton crushed per day now it has increased to 4000 tons/day. It is located near Vithewadi village, in the toposheet number 46/2 of the survey of India and lies between 20° 27' North, latitude and 74° 10' East, longitude. The area receives average rainfall around
500 mm. hence the climate of the study area is generally observed dry wet. The maximum temperature during summer reaches as high as 38°C whereas minimum temperature is as low as 9°C during winter.

The industry requires nearly 3000-3200 liters of water/ton/day. With all internal processes in the industry, the water after partial or without any treatment comes out as an effluent. This effluent goes through natural stream flowing through the agricultural area. While flowing, the effluent percolated in the soil, nearby wells and bore wells and adversely affected the soil and natural ground water quality.

It was observed that groundwater in the area occurs under water table condition in the weathered permeable and porous zeoltic basalt. The groundwater in the basaltic aquifers was predominantly tapped by dug-wells in the study area at a distance varying from 50 to 350 meters. The dug well was ranged in depth from 33 to 57 feet (10 to 20 mts) in the western part of the study area, but in general the depth of the wells was uneven throughout the area. The diameter of the wells varied from 4 to 11 meters. Most of the wells were lined indicating higher thickness of alluvial and weathered basaltic aquifers. The depth of the water table was varied from 1 to 16 meters in the area. The result on water and soil are summarized as.
Physicochemical Characteristics:

The pH ranges from 5.2 to 8.9 during the study period. However, the average pH values for all the seasons showed minimum pH 6.3 to maximum up to 7.8 pH. In general, study area showed alkaline pH for all the water samples except few of the wells in every season during the study period.

The effluent of the sugar factory showed slightly acidic pH i.e. 5.2 due to different processes in industry like cleaning of the machinery addition of sulphur for obtaining white crystal of sugar in the process etc.

The electrical conductivity vary from 316 (W9) to 4960 (W5) mmhos cm\(^{-1}\). Similarly during off period of the sugar factory the EC ranges from 316 to 1700 mmhos cm\(^{-1}\) and during operational period it varies from 440 to 2780 mmhos cm\(^{-1}\). The effluent sample showed more EC i.e. 4319 mmhos cm\(^{-1}\) than almost all the water samples except well number 5 in summer season during first year of the study period which shows EC up to 4960 mmhos cm\(^{-1}\). This is because ions from effluent were entered in these wells. The low values of Ec may be due to lower temperature and stabilization of water due to sedimentation. The average TDS concentration for entire period was 367 to 1448.5 mg/s. During off period of the sugar factory the TDS content in water varied from 263 to 1193 mg/l and during season it
was between 210 to 3216 mg/l. This inturn increased the salts of Ca and mg in water which were responsible for total hardness.

The total hardness varied from minimum 95 (W 3) to maximum 336 (W 6) mg/l. During operational period of sugar factory hardness observed to be minimum 82 (W1) mg/l and maximum upto 336 mg/l. On the otherhand in off season (i.e. February to April) it varied from 80 ( W6) mg/l to 312 mg/l (W 8). The effluent of factory showed hardness upto 624 mg/l. In general water from the study area was categorized moderately hard to very hard.

**Indicator Parameters:**

The DO values in summer season varies from 4.8 mg/l (W 10, W 11) to 7.6 (W 2, W 17 & W 18). In monsoon it varies from 4.6 (W 8) to 6.8 mg/l (W 21) and in winter it varied from 4.2 (W 8, 20 & 21) to 8.0 (W 4 & W 17) mg/l during the first year i.e. in 2008-2009. However, during second year i.e. 2009-10 it increased in summer from 4.5 (W 18, 21 & 22) to 8.0 (W 19) mg/l in monsoon, from 4.3 (W 8) to 7.8 (W 3) mg/l and from winter from 3.2 (W 20) to 8.2 (W 3) mg/l. The DO values of sugar factory effluent in summer and winter season during the study period was zero while in monsoon it was just 1.2 mg/l during first year and 1.7 mg/l during second year of the study period. The observed low values of dissolved oxygen in water in the study area might be attributed to input of organic
pollutants causing anoxic conditions due to the decay of organic matter.

The maximum values of DO are probably allotted due to progressive lowering of organic turbidity due to photosynthetic activity and circulation of water, similarly lowering in the temperature of land surface water body as well as organic waste input in the water body which has a very complex and unpredictable influences on dissolved oxygen.

The BOD was maximum 14.6 mg/l in summer season during the first year study period whereas minimum; 1.2 mg/l in late summer during the second year of study period. For both the years of study period BOD values ranged from 1.2 (W 20) to 14.6 (W 12) mg/l in summer from 1.5 (W 21) to 13.0 (W 8) mg/l in monsoon and from 1.9 (W 7) to 12.8 (W 20 & 21) in winter season. The BOD in the effluent of sugar factory was increased upto 940 mg/l in summer while the demand of biological oxygen was fallen down upto 6.24 mg/l in winter season, thus these values are suggestive of possible mixing of organic pollutant in the water gives an idea of quantity of biodegradable organic substances in water.

In general the COD showed a similar trend as that of BOD with the highest value of 28.8 mg/l. Therefore it has given the idea that higher BOD and COD values in ground water lowered the DO values.
In case of effluents, the values for these parameters are quite high. Hence it was attributed that the groundwater in the area showed only a trace of organic pollution. This was clearly evident from the low phosphate and nitrate values in the well numbers 5, 6, 8, 9, 10, 11, 12 and 13. These wells were in the close vicinity of the sugar factory and the stream carrying effluent and hence the organic pollutants traveled to a short distances and affected the quality of groundwater over large area.

**Anionic Constituents:**

Alkalinity has acid neutralizing capacity of water, which depends on the strength of carbonates in sample and it determines the availability of free carbon dioxide which is essential for photosynthesis and thus is directly related to productivity. The total alkalinity varied from 92 (W 11) to 450 mg/l (W 5, W 12) in summer, from 128 (W 11) to 450 (W 8) mg/l in monsoon and from 99 (W 1) to 420 (W 20) mg/l in winter season for both the years of study period. The effluent showed maximum alkalinity upto 2914 mg/l in monsoon and minimum 503 mg/l in summer season, which indicated high degree of pollution of water is harmful for domestic purpose, irrigation which leads to soil damage and crop yield and imparts bitter taste to the water.
Seasonal variations of sulphate were varied from 65 (W 21) to 158 mg/l (W 12) in summer from 20 (W 12, 21) to 206 (W 1) mg/l in monsoon and from 10 (W 21) to 79 (W 8) mg/l in winter season. The effluent showed sulphate content upto 43.8 mg/l in summer, 37.8 mg/l in monsoon and 41.0 mg/l in winter season. From the results it is observed that in off period of the sugar factory the sulphate content was found to be lower than operating period in some of the wells i.e. well number 4,5,6,8,11 etc. as these wells are located in the down gradient direction in the vicinity of the effluent stream as well as highly irrigated patch of the area. The sulphate may concentration in the effluent of sugar factory was recorded as 43.7 mg/l i.e. very low as compared to well waters. Therefore it is interesting to note that in the absence of effluent as a source the sulphate may come to water by a variety of other anthropogenic conditions in the form of sulphate rich fertilizers since the area is highly irrigated. High concentration of sulphate and sulphide with high chloride, nitrate and phosphate associated with depletion of oxygen led to anoxic condition in waters.

The chloride content varied from 032 (W 19) to 980 (W 7) mg/l in summer, from 048 (W 14) to 942 mg/l (W 8) in monsoon and from 040 (W 19) to 215 (W 10) mg/l in winter season. The effluent showed chloride content upto 361 mg/l in summer, 323 mg/l in monsoon and 328 mg/l in winter season. The higher concentration of chloride may
be due to anthropogenic activities and addition of chloride rich fertilizers in the area. The rising concentration depends upon dumping of effluents from industrial processes as well as human activities.

**Minor Constituents:**

Phosphate was observed below 1 mg/l for all the seasons. Even during off and on-going period of sugar factory the level of phosphate remains below 1 mg/l. However, effluent showed 4.58 mg/l of phosphate in summer, 7.6 mg/l in monsoon and 4.73 mg/l in winter season. The concentration is much higher as compared to all the well samples in the study area. Low values of phosphates observed in the study area may be due to the fact that as tropical water always possess low concentration of phosphate.

The concentration of nitrate varies from 0.001 (W 3, W 17, W 19) to 0.312 mg/l (W 15) in summer, 0.001 (W 7, W 12 & W 21) to 1.15 (W 11) mg/l in monsoon and 0.001 (W 13) to 0.92 (W 11) in winter. The average concentration of nitrate ranges from 0.001 to 1.20 mg/l. The effluent showed maximum nitrate upto 11.6 mg/l. However the maximum average concentration of nitrate shown by water from Well No. 11 is up to 1.15 mg/l. This can be attributed that this well is located to down gradient direction of the effluent stream.
Cationic Constituents:

The values of calcium are as high as 150 mg/l in (W 9) in monsoon season. The lowest values of calcium were observed in the well No. 6,8 and 11 with the values of 10 and 14 mg/l in summer season. In sugar factory effluent the calcium concentration was upto 321.0 mg/l. The high calcium content in the effluent can be related to the oxidation of organic matter releasing free calcium in the solution in the acidic pH.

The average concentration of magnesium for ground water was found below 26.0 mg/l. As against this the effluent showed magnesium upto 29.0 mg/l. Hence, the wells which has shown concentration of Mg upto 10 mg/l or above that along with higher calcium values was considered to reflect the contamination of ground water due to the effluent. Further, it was observed that the concentration of sodium was ranged from 45.0 (W 1) to 336 (W 6) mg/l. It was interesting to note that the average value of sodium for the groundwater was higher than that of concentration of sodium in the effluent. This has indicated that apart from contamination of ground water from the effluent the natural process, which increase the sodium concentration in water, are more important. The potassium in the ground water showed lower values i.e. below 21.0 mg/l for most
of the sampling wells, which are due to the absence of potential source off in soil but reflected the use of potash fertilizers in the area.

Spatial relationship:

It is found that sudden increase in the Na\(^+\), Ca\(^{2+}\), K\(^+\), Cl\(^-\), HCO\(_3^-\) and SO\(_4^{2-}\) at well numbers 5,6,8,11,15,20 and 22 give an idea that their water was affected due to addition of some constituents of anthropogenic origin. This may be due to the location of these wells in the down gradient direction of the effluent disposal stream as well as in the close vicinity of the press mud dumping station. The indicator parameters were observed following same trends as major constituents. Hence, it was concluded that the wells 5,6,8,11,15,20 and 22 received organic pollutants from effluent from the factory area as it was rich in COD and BOD levels.

However, the spatial variation in the concentration of minor constituents i.e. PO\(_4^{2-}\) and NO\(_3^-\) along the cross sections A-A’ and B-B’ do not follow the same trend as that of major and minor constituents.

Chemical Relationship:

The Piper’s Trilinear diagram showed that in 52.17% wells, the weak acids (HCO\(_3^- + CO_3^{2-}\)) exceeded strong acids (SO\(_4^{2-} + Cl^-\)). Whereas rest of the wells were dominated by strong acids. In case of ten well (well numbers 19, 11, 14, 13, 3, 20, 21, 22, 4 and 5) non-
carbonate alkali. i.e. primary salinity exceeded 50%. This indicates the fact that the chemical properties of groundwater dominated by alkalies (Na\(^+\) + K\(^+\)) and strong acids (SO\(_4^{2-}\) + Cl\(^-\)). On the contrary, twelve wells (well numbers 16, 1,7,6,8,10,2,9,17,18,15 and 12) showed the chemical properties dominated by alkalies and weak acids (i.e. carbonate alkali exceeds 50%). It was observed that alkaline earths and strong acids however, dominated in the effluent of the sugar industry.

It was also observed that for summer season for 2008-2009 and 2009-2010 dry season or off-season of sugar industry (i.e. February 2008 to April 2008-2009) strong acids exceeded weak acids. On the other hand during the winter season i.e. (wet season or operational period of sugar industry) the weak acids exceeded strong acids.

**Appearance of salts in water:**

Uncontaminated wells (Group ‘I’) which represented natural basin groundwater have showed lower Na\(^+\): Mg\(^2+\), Ca\(^{2+}\): Mg\(^2+\) and Cl\(^-\). HCO\(_3^-\) ratios as compared to group ‘II’ wells belonging to contaminated groundwater zone in downstream direction of effluent stream. However, the ratios for the effluent were in close agreement with group ‘II’ wells except Na\(^+\)/Ca\(^{2+}\) ratio. The values for Ca\(^{2+}\)/Mg\(^{2+}\) and Cl\(^-\)/HCO\(_3^-\) for effluent and group ‘II’ wells were almost the same, suggested that most of the group ‘II’ wells were receiving ions into
the groundwater from the mixing of effluents. This was because, the natural basin groundwater (group ‘I’ wells) have much lower values of these ratios indicating an interaction of groundwater only with the host rock minerals. The changed values of the ratios for group ‘II’ wells were, therefore, considered as an indication of the effluent as potential source of contribution of groundwater. The elevated values of ionic constituents for well numbers between 13 to 15 sections A-A’ clearly reflected the nature of lateral extent of plume on either side of the stream. Therefore, the zone of pollution was demarcated had aerial extent of 3.32 square kilometers.

**Quality of Water:**

The comparison of different parameters of water with WHO and ISI showed most of the parameters were within the limit except TDS which showed values from 1903 to 1448.5 mg/l in well number 5 and 8. The increase in TDS values may be due to contamination of groundwater from the effluent. However, effluent showed TDS within the limits for its disposal on lands for irrigation. Disposal of such water on surface had thus, given rise to groundwater problems, resulting in unacceptable quality of groundwater for drinking purpose. But groundwater quality was satisfactory for pet animals like cattle (dairy), sheep etc.
The SAR values are below 10 for all the sampling wells in all
the seasons during the study period except well numbers 5,6,7,20,21
and 22 in summer, well numbers 8,9 and 22 in monsoon and from
well numbers 9,10,21 and 22 in winter seasons of the year 2008-2009.
While, during the period 2009-2010 the well numbers
4,6,9,12,14,15,16,18 and 21 in summer, well numbers 8,9,10 and 15
in monsoon and well numbers 9 in winter season exceeded the value
10. Thus, water from the study area may be graded excellent to fair
for irrigational purpose on the basis of SAR.

The RSC values varied from 0.93 to 5.94 meq/l, which showed
that the natural basin groundwater was marginally suitable to
unsuitable for agricultural use. It was noted that the RSC of most
wells from the zone of contamination had values less than 3.5. This
was particularly due to the fact that the sugar mill effluent was having
Ca$^{2+}$ as a predominant constituent, which on mixing with Na$^+$
dominated groundwater had resulted in ion exchange reaction leading
to decrease in Na$^+$ hazard to the soils from the area.

The SSP and KR values for more than 80% wells were above
50 and above 1 meq/l respectively. This may suggest that the
groundwater was of very poor quality to be used for agricultural. This
will likely to develop alkali hazard to the soil in the area. The effluent
sample shows KR below one and SSP less than fifty suggested its
good quality for irrigation. Use of this water for agriculture will therefore help in reducing the problem of alkali hazard to the soil posed by natural basin groundwater.

**Soil:**

The pH of soil was above 7.0. It was ranged from 7.18 to 9.89 reflecting alkaline nature. The EC values of saturated paste of different soil samples were observed less than the 4.0 mhos Cm-1. The soil from study area was categorized as non-saline alkali type as ESP values were above 15 meq/l and the pH values were also above 7.5 in most cases.

The CEC of the soil varied from 28.31 to 75.5 meq/100g. Therefore, the soils in the area were texturally classified as clay loams to clayey. The values of CEC were very low as compared to the total exchangeable cations. This variation was possibly being due to the clay and organic matter content of the soils. However, in general CEC values of the present soil were high and hence it was expected to consider indication of hallo site to montmorillonite clay bearing soils that was categorized salty loam to organic soil.

The higher values of SAR (5.59 to 24.3 meq/l) for most of soils indicated possible loss of permeability in soils. Therefore, these samples represented the grade of soils belonging to alkali types.
The ESP values were ranged from 6.21 to 22.34 meq/100 gms which is indicative of alkaline and non-alkali nature of soil. On the basis of spatial variations in the ESP values the boundary between alkali and non-alkali soils in the study area was demarcated.

Out of the total exchangeable cations the Ca$^{2+}$ was found to be highly exchangeable (31 to 60%) than other three cations viz Na$^+$ (10 to 31%), Mg$^{2+}$ (08.0 to 13%) and K$^+$ (2.3 to 10.20%). The sample number 7,8 and 9 showed equal amount of exchange of Ca$^{2+}$ and Na$^+$ cation (31%) which indicates Na-clay and Ca-clay saturation giving rise to alkali soils in the area.

**Water in relation with soil:**

The pH of water showed significantly positive correlation with EC, SAR, ESP and exchangeable Na$^+$ of soils. Similarly, the EC of irrigation water showed strong positive correlations with SAR (r= 0.80) followed by SSP (r= 0.55). The SSP of irrigation water is positively correlated with pH (r= 0.60), EC (r= 0.55) and SAR (r= 0.80) of water. Its moderate positive correlation with all the soil properties is obtained.

On the other hand, the RSC of water showed strong positive correlation with properties such as pH (r= 0.68), EC (r= 0.98), SAR (r= 0.78), ESP (r= 0.72) and exchangeable Na (r= 0.74) of the soils. Weak but positive correlation of RSC with SSP of soil (r= 0.40) was
also observed. This indicates that RSC of water was one of the most important parameters that govern the properties and hence quality of the soils. The RSC was therefore, used for predicting the EC of soils and hence for classifying the soil as saline or non-saline. Next to EC, the RSC of water showed significant positive relation with exchangeable Na\(^+\) and ESP of the soils \((r=0.74)\) and \((r=0.72)\) respectively. The positive correlation between RSC of groundwater and ESP as well as exchangeable Na\(^+\) of the soils suggested that there was an appreciable amount of soluble carbonate and bicarbonate affecting the soils.

The sugar mill effluent contaminated the local groundwater aquifer was highly charged with dissolved carbonate, which was the main source of excess soluble bicarbonates in the irrigation water. The amount of Ca and bicarbonate added by the effluent in natural groundwater therefore lead to saturation of water with calcite. Therefore, those irrigation waters having less than 2.5 meq/l of RSC are expected to take comparatively longer period of time to raise the ESP to a critical level of 15 in the soil of the study area.

The, ESP of soil had governed by SAR of irrigation water. The value of correlation coefficient for this parameter in the area under study was moderate \((r=0.40)\) suggested that ESP of the soil was partly governed by SAR of irrigation water.
From the study it is concluded that the groundwater charged with sodium, calcium, chlorides and sulphate are responsible for the concentrations of total dissolved salts. The high value of calcium might be due to oxidation of organic matter on reducing free calcium in acidic pH. Similarly high value of sodium may be due to non-uniform mixing of rain or irrigation water with natural basin groundwater. The weathering of primary silicate minerals from the basalt and dissolution of secondary bicarbonate might have increased the concentration of alkalinity due to reaction of water with augite and plagioclase i.e. chief source of supplying major ions has given the idea about their occurrence in the groundwater. Therefore, in absence of any lithological variation there should not be higher concentration of these inorganic ions. It also confirms that such ion comes in the water through anthropogenic activities like industrialization and inadequate agricultural practices. The presence of COD and BOD and depressed DO in well waters again confirm the fact that some organic impurities also reached in well water. Hence, pollutant both inorganic as well as organic might have travelled to some wells in the study area, which might have changed the chemistry of well waters. This is supported by effluent giving the higher values of Ca$^{2+}$: Mg$^{2+}$ and Cl$^{-}$: HCO$_3^-$ ratios than the background well. The effluent may have travelled long distance as the aquifer in the area is directly in
hydraulic contact. Due to this fact, the streambed of effluent has favoured induced infiltration of water and established the influent stream condition as groundwater in the area is continuously extracted for agriculture. Hence, the ions from effluent have been drawn rapidly in the wells. The infiltration of effluent through soil and weathered basalt evidently caused the contamination of groundwater. The elevated values of ionic constituents in some wells clearly reflect the nature of lateral extent and the movement of plume on either side of the stream in study area. This is supported by the hydrochemical facies, indicating about 52.17% wells showed weak acid ($\text{HCO}_3^- + \text{CO}_3^{2-}$) exceeds strong acids ($\text{SO}_4^{2-} + \text{Cl}^-$) and in rest well water reverse the condition. During off-season of sugar industry strong acids exceeded weak acids, on the other hand, during season or operational period of sugar industry the weak acids exceeded strong acids. This confirms that the water after mixing with effluent become rich in carbonate, sulphate and calcium. Thus, water from study area has been changed through physical, chemical and biological quality. Therefore, it was observed that water in some wells was not useful for drinking purpose, but it could be used for livestock purpose like cattle and sheep. However, the values of SAR, SSP, RSC, and KR for water in most of the wells showed water is good for irrigation under certain conditions. But higher values of SAR coupled with ESP may pose the
sodicity directly in the water and indirectly in soil. The soil supports this fact by giving pH in alkaline range and EC in non-saline alkali condition. Therefore, possibly there will be loss in permeability of the soil. However, CEC suggests that soils in the area are of kaolinite, hallosite and montmorillonite clays. The ESP has clearly demarcated the boundary between alkali and non-alkali soils in the area. The RSC effluent suggests its good quality for irrigation because of more carbonate and calcium content. Therefore, the effluent having low RSC will help to solve the problem of alkali hazard posed by natural groundwater in the area.