Environmental Quality: Monitoring and Analysis
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Lecture – 11
Introduction to Environmental Monitoring and Sampling

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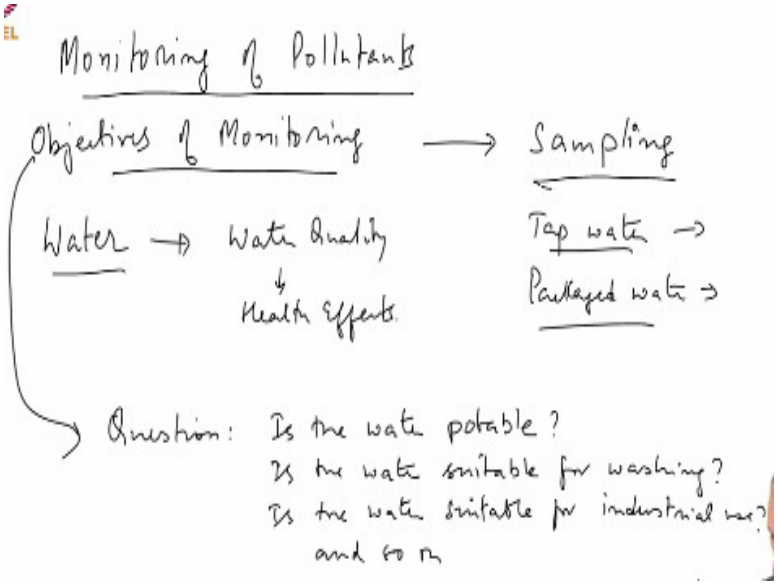

So, we will start looking at monitoring. We will take some time, so some of these concepts that you have looked at it preliminary in a very simple fashion will also apply here. So, monitoring is the main step because anything we want to do, we have to measure. The first step in the environmental sequence of things that we talked about is monitoring. So, the first thing you want to decide or to discuss is what are the objectives of monitoring. You can't just go blindly into monitoring scheme without knowing why you are doing it, what is the objective? So objectives could be many things. So as we go further into the topic, we will refine this definition, objectives. Right now for many of you may not be very obvious what the objectives could be, but we will discuss that briefly. So, let us take the instance we are taking the case of water. Why do you want to measure water quality and we discussed this long back in the beginning of this. We want to measure water quality because we are worried that there may be any health effects from it. So, we would like to look at the water quality from a point of view of health effects. So, which means that we are specifically we want to look at some target components in the water which we know have a problem, okay. So, when we do monitoring, implicit in monitoring is this issue of sampling, yeah. What do we mean

by sampling? Monitoring is you are measuring a component or multiple components in a given sample of water.

But then where do we sample? which water should we take? And what are the problems and questions that we need to ask in terms of this? So for simple example you want to drink water, what water will you sample? You are going to sample whatever you are drinking, right. So, if you are drinking tap water, you will sample tap water, yeah. If you want to drink tap water, you will say is tap water safe to drink? Therefore, I will sample tap water and find out if the components are there. What is the composition and what is the concentration of these things? And therefore I will decide whether tap water is safe to drink. If tap water is not safe to drink, then I will look at you know package water and then test it and so on. So, it will keep going back and back. See so the idea of monitoring is linked to the end use of this and then we say is this particular type of water suitable for a particular application, is it suitable for washing, is it suitable for taking bath or is it suitable for industrial use and so on.

So these kinds of objectives are very important, okay. So one must ask a question, the objectives of monitoring requires us to ask a question, form the monitoring question, what is it that here we want, so here is the question could be, “is the water potable?” So it’s a very simple question. When we say it potable, we are defining the quality of water for potability. So, in the CPCB website and the EPA website you have these qualities that are listed there that what is potable water, certain characteristics must be there, it must be below this value and so on.

So this is the monitoring question. So this will lead to the other follow up activity that we want to do. Is the water potable? Is the water suitable for washing? Is the water suitable for industrial use? And so on. So, if you look at this question from a point of view of how critical it is to ensure quality, you are decreasing in the order, so you are saying potable water is the highest order, so I will keep it at the highest level. The rest of it is lower quality than the other, in any case so this relates to where you are going to sample it and all that. So, this is end use water that we are talking about. We are also looking at sampling in the environment.

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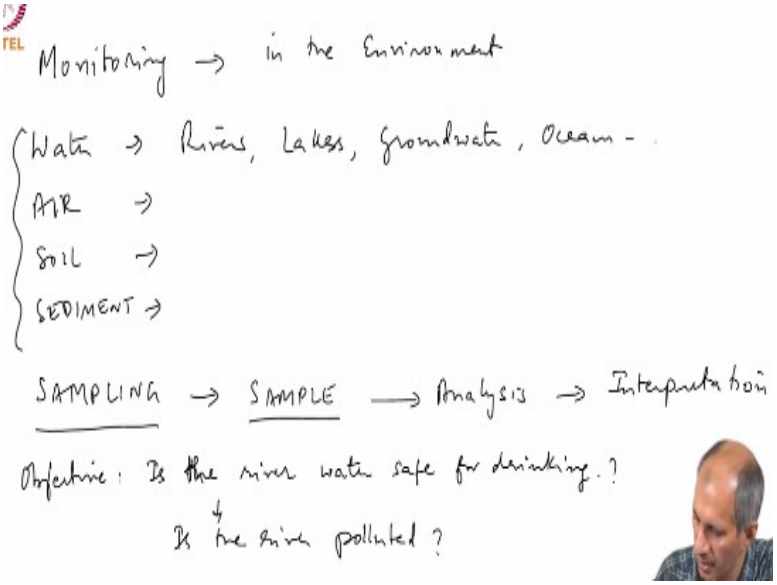

When we say monitoring, we are also monitoring in the environment which means we are going back further to the source of some of these things, we are looking at the environment itself. So, when we are looking at in the overall scheme of things in the beginning we discussed where we have health effects are observed in receptors then we go and see what is causing it, which means we have to monitor what is it that? We analyze the air, the water, and food and everything and we go further back and we say is this there in the environment? it's coming from the environment somewhere.

So, we have to monitor in the environment. So, which means that we are monitoring in for example, we monitor water, we are monitoring rivers, lakes, groundwater, all these things okay and then oceans and so on then we look at air, we look at soil, we can look at sediment, and so on. So we are monitoring in all of these, okay. So, when we monitor in a river for example, the first step in monitoring is sampling, which means you have to have a sample.

The word sample is a reserved keyword, sample means it has a special status, sample is whatever is it that you want to analyze anything that is a sample. So, what constitutes a sample determines what information you'll get out of it and what you make out of it, how you interpret that information. For example, if you are looking at my objective, is the river water safe for drinking? yeah, very simple question.

By experience we may know that it may not be useful for drinking, but at priory you do not know, if say 100 years back people used to drink directly from the rivers and all that, 400

years back or whatever time back, so but this is a valid question. So now the follow up question will be or other question will be is the river polluted? Yeah, okay.

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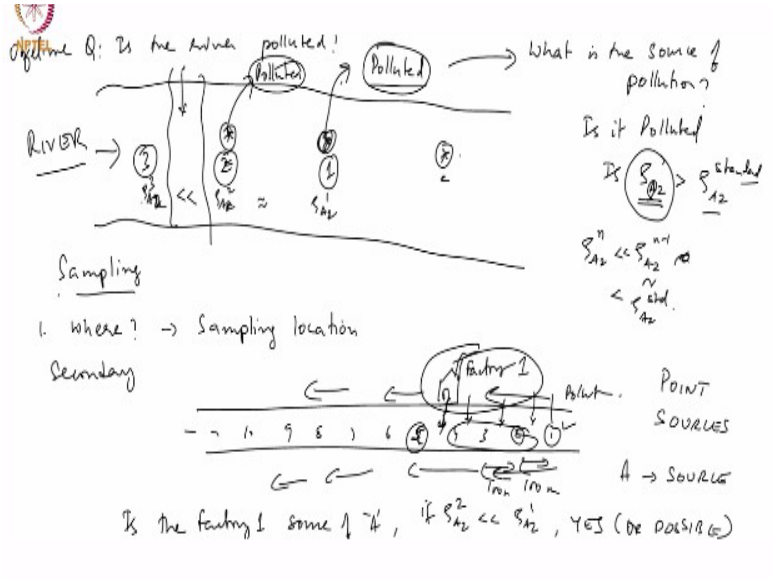

Now in this question, where will you sample? So I have a river that is flowing then I need a sample of water from this, so where will I sample? So the question is sampling location. Where will I sample in a river? You have a lot of choices, right. If my objective question is simply, is the river polluted? A very general question, where will I sample for this? Anywhere, okay. So, let's say I will sample here, this is my sampling location.

I take the water out of this and then I go through the process of analyzing I will get some results and let's say I have some concentration, let us say based on the concentration I determined that it is polluted okay. Is this the universal answer in the sense what will you do with information? So you determine that it is polluted from sampling here. So you go and tell whoever is the agency that controls the river they say this river is polluted, then what will their response be?

If you are a user or you are a regulator or an administrator. What are the other questions that you can ask? Find the source of the pollutant, so that becomes a new objective now. So, how do you find the source of the pollutant by using monitoring? You have a secondary question that has now appear based on this polluted you will find what is the source of pollution, this is now a new sampling objective. What will you do now for this? Where will you sample? It is a difficult question, where will you sample now?

Naturally, from a very simple common sense point of view, where will you sample? This is a river, which means where will you sample? Upstream. So, where you sample, very simply the sample before here or after here. Two possibilities, either downstream or upstream, this one or this one where? So, why do you think upstream is more useful than downstream? River is flowing, flowing somewhere, so if the pollutant is here, it is all coming from somewhere else.

So, we would like to find out where is it coming from, so what would you do? How will your sampling plan now be? A very straightforward question, you do not need to be an engineer to answer this question. Simply what would you do? How many samples will you take? Two, take it here? What will be question you are asking here when you sample? I have to determine if it is polluted or not? I have to say yes or no, it is polluted or not? Here, sampling point number 2, I will ask the same question. Is it polluted or not, which means that I am applying some quantitative criteria to ask the question itself. When I say is it polluted? Itself my question is, is the concentration of water greater than some concentration of some standard, this is the question I am asking, I am determining this information and comparing it with something and let us say this is more than what is acceptable.

Therefore, I consider it as polluted. I am doing the same thing here. What if I find that ρ_{A2}^{2} is almost the same as ρ_{A2}^{1}? Then what can I do? I will go further, I will take one more sample, so I have to keep going, and comparing this again. I keep going further and further down until the point when I see that some ρ_{A2}^{n} is less than ρ_{A2}^{n-1} or it is much less than ρ_{A2}^{n-1} and also or $\rho_{A2}^{standard}$ either of these things.

Then I know that somewhere between let us say that ρ_{A2}^{3} is much less than ρ_{A2}^{2} which means that somewhere in this region, my source is present. So this is an investigative process, what are the constraints here? So let us say that I have a river that is where I find first sample I do here, I find pollution, right. How far can I go? You have to make a decision that the second sample is how far from the first sample. What is the easiest way for me to do it? Simple, with no thinking, what would you do?

So, theoretically I can go do 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 keep on going, say I will do every sampling every 100 meters okay. Every 100 meters I can sample. Is this necessary? So, the assumption here is that within 100 meters there is some source that may be coming. Instead

of doing it randomly at hundred meters' distance, you go and look what is there on the shore both side, what could be possible sources of contamination i.e., physical examination.

So you check if there is physically anything that can contaminate. So, we call these as point sources. Point sources is applied in air pollution prominently, but this is what we are calling here is point source of water pollution, which means that there is a fixed source here. Fixed source means there is say a factory, there is an industry or something, some manufacturing plant and there is a possibility that this will go here. Now, you can make a judgment very easily. So, one of the things you have already done, you already have information of ρ_{A2}, which means you already know what this A that you are looking for.

A is some pollutant right, something. In the scheme of things, I can do an analysis for hundreds of chemicals and I say that this is there, A is there. When I say ρ_{A2}, it does not mean only one parameter, it means we are doing entire analysis, I am analyzing for say hundred parameters, hundred chemicals, metals, nonorganic, microorganisms everything. So, I know that there is a possibility of A with one of these components that now can cause health effects, where can that come from.

So, this A linked to a particular source. For example, if you find mercury in the water, there must be some source of mercury that is appearing in the water that is contributing to this. So, when you go and look on this along the river, is there anything, any process that can contribute mercury? So this information is needed it's an external information, this information involves you to know the list what are the possible sources, points sources.

You have list of industries, where one industry is battery industry or there is a company that is making bulbs or a company that is making something else, electrical components, all these things. So there are components, you can make a list of these things, and then say possible emission of these things. So let's say a factory is here, I can skip all of this, I can go directly to something upstream of this factory. So my question now is, is this factory causing the pollution?

Which means that I will sample at one (downstream of the factory), the second sample now be somewhere little upstream, and then if I ask the question if factory, let us call it factory 1,

source of A. If ρ^2_{A2} is less than ρ^1_{A2}, the answer is yes or possible. See the answer is never yes or no, it is not that straightforward. We will come to that in a bit. I say yes, possible, this is one answer.

So, when you get results like this, immediately you know and you go and sample further upstream little more to confirm that this is true okay, and when this is true, then you again confirm it again, you see this is happening again and again. This is sampling objective. So, then we make a statement that factory 1 is responsible for this contamination. The objective of the sampling initially is to just find water quality and then it has converted into finding out the source of the pollution.

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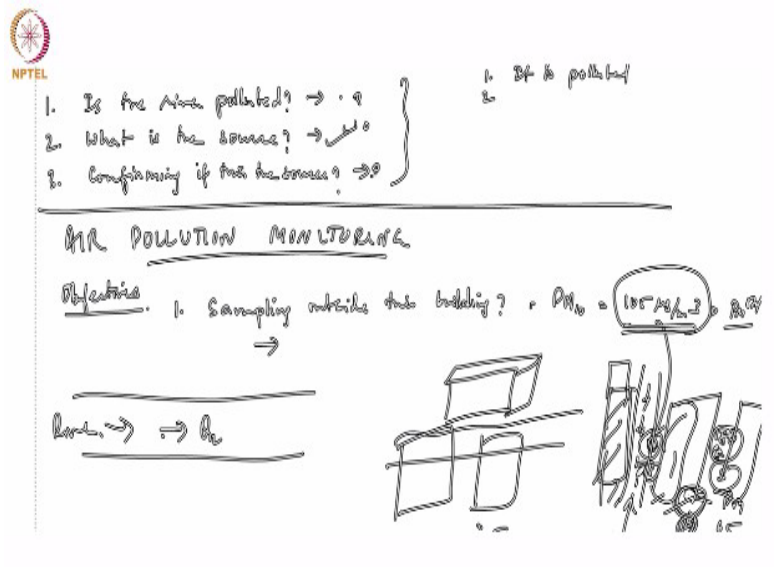

Then further in this problem itself our questions started from is the river polluted? To begin a second question, what is the source? Then the third follow up question is we are confirming it is a source. All these 3 questions need sampling, but the objective has changed in each of these questions. Now, we are looking at very different things. The first question, is the river polluted is a very general question. I have no idea what I am looking for.

So the first question itself you can modify nicely by doing the analysis along the river and then say these are the possible pollutant, I know the information that this is going to happen and these are the pollutants that are likely to come into water and therefore look only for them straightaway. I may define my water quality criteria based on that okay. Why would one want to do this, so if you are government agency, you have so many rivers and so many lakes, so many things to take care of. You cannot go and keep doing individual analysis. So

you are generally looking at water quality as the overall parameter. So you won't be doing 100 chemical analyses on that. You will generally be doing COD or BOD and generally you will say that some water quality is not as good as what I would like it to be. I do not know what it is, I will leave it there. Based on that limited information itself says you can say that one particular source is contributing to the water quality impairment than the other without even going to very specific.

For example, in the previous case, here I am looking at A, this A can simply be COD or BOD, it need not be a specific chemical and this could still be true that the COD here is much lower than the COD here, which could still mean that factory 1 polluting, we just do not know what it is, but here we are not doing a very specific matching, in the sense we are not saying A is particular chemical and this chemical is coming from factory 1 and therefore it must be factory 1 that is polluting.

We are saying, there is a factory which may pollute, let me go and check. This is the level of this thing you are doing, okay. The other type of sampling objectives that you can have is, this is much more easy to understand if you are looking at air pollution because there it is much more complicated. The river is very straightforward going from point A to point B, yeah. The atmosphere is much more complicated. So, let us say that you always say do air sampling, do air sampling, yeah, where will you sample that is the question?

This question of where you sample becomes very, very critical in air pollution. Because of the nature of air moves, you cannot even see it first of all, you can feel it, but it does not mean anything. So, then the objectives become very, very important. So, in the case of air pollution, you see a lot of statements about air pollution in the public media all the time, again people take information that you give and use it for whatever the people want to use it for whatever they understand, that is not really a mistake.

It is not intentional thing, but sometimes you do not know what it is because you are not aware of the system, okay. Give me a few objectives air pollutions and monitoring objectives. What could your question be? How will you frame your question? Same type what we did quality, same rules apply, the same concerns apply, but the way in which we do becomes more critical way, the sampling and monitoring becomes very critical here and the

assumptions that we do and it is also true for water, we will go back to what a little bit after we discuss this and then we will define that okay.

Now, let me give you a simple example. We have a road in front of this building, okay. If I go and sample the air outside this building, what will the data mean? There are a number of follow up questions to this, okay. What is this data? What does it mean if I sample air? If I go and sample there, I will give you a number, I will say PM 10 concentration is let us say 105 micrograms per meter cube, some number. What does this mean? I am giving you a number, it has to mean something, what does it mean? There is standard. So let us say that is greater than PM standard, yeah, but in a sense, when I am doing this sample, what is my follow up concern. So what is the simplest inference I can make from this? Yes, it is causing health effect, then what is the follow up this thing, what is the source that is there?

But before we go to the source itself, what is the difference between the river and air. There is a river that is going in this direction and there is a general air mass that is in front of a building in a road like this, which means that we have tall buildings and there is a road that is going in between and there is another tall building here. So, there is a road going in which there are lot of buildings and I am sampling here. This building is say 3 storey, 4 story high. When I sample here, can I extend it to anything else? The wind direction. I will measure the wind direction. Let us say the wind direction is in this direction, yeah. What does this represent? A concentration of 105 micrograms per meter cube, what does this represent in general? Because the objectives of the sampling become very important here. The difference between river system and air system, do I know everything about the air system?

This one (river system), I know a lot more information about this (river) than this (air) because I know there is a river, there is a flow and I probably know this is the flow rate, which is common which can be measured easily. Here, if I want to know what this means, what could this mean? Let us put the question this way. What could this mean, one is already said it is polluted, that is fine. Anything else that you can infer from this piece o f reading? Let me give you a contrast.

Suppose I am sampling here, I go and sample on top of this building and I see I get a PM reading of 65, what does it mean? When I sample between these 2 buildings, I get a reading of 180. These 3 are all very close together. The distance between each of these locations is

hardly 100 meters from each other, but there is a difference, there is a possibility of big difference in the reading of this three samples, what does it mean? Flow rate of air may be different, okay.

How does that change the concentration? So, if you see such data, what is your next immediate thing? What will you do? You cannot make sense of this data, which one will you report? Why not on top of the building and why here (bottom) and why not here (top)? See, depending on which way I want to turn the debate, I can say that I can use this number and say it is very polluted 180, very highly polluted. So ban.

So then you will go and find out what the sources and then you say I will ban all vehicles in the campus, I will ban this, I will ban that, everything is closed, done, but then what does this mean? The 180 here it should mean something, but this is 100, this is 180 and this is 65, somebody else can use 65 as the value and say everything is fine, no problem, everything is okay. This is the problem. This presents a very important question in terms of why you are sampling and what is the objective and what is the meaning of that particular value? Yeah.

So, there is something more to this, what is that? I'm trying to ask you what is that, so very simply this is true to all analytical studies, you cannot make an inference from one particular sample, which is why all environmental scientists do what is called as a time series. Especially environmental systems, we do not know why something is happening. If you know everything exactly why something is happening, then you can find out exactly you know what is the cause of high concentration or low concentration?

If you do not know why it is happening, but we still cannot stop doing anything, we have to stop, so we do what is called a time series. So, in order to understand this, very simply the information about these 3 can be sorted out by looking at the second question that we did. We look at what is the source? What are possible sources? Okay. So, here is there a higher source than what is there in this case? So we call it as again sampling location 1, 2, and 3.

So, is there is something in 1 that is not there at 2 and there is something at 3 which is not there at 1 and 2 or additionally there is something there in 3. This is at (sample 1) ground level, this (sample 2) is about 2 or 3 storey higher or 100 meters high and sample 3 is 100 meters away, but it is inside somewhere. So, this is exposed to some sources, there are

vehicles going here and you can say that 100 is because there are vehicles happening, the vehicles are the source of pollution, yeah.

So this is inference you make, the vehicles are a source of this pollute. What about this one? What about the 65 here, second one, up in the air, top of the building. There are no vehicles nearby. If this was also 100, then you can say that whatever is happening here (near sample 1) is seen here (at sample 2) also. So this source, whatever the source that is contributing to this also is contributing to this possibly, the only way to confirm that is you keep doing this again and again.

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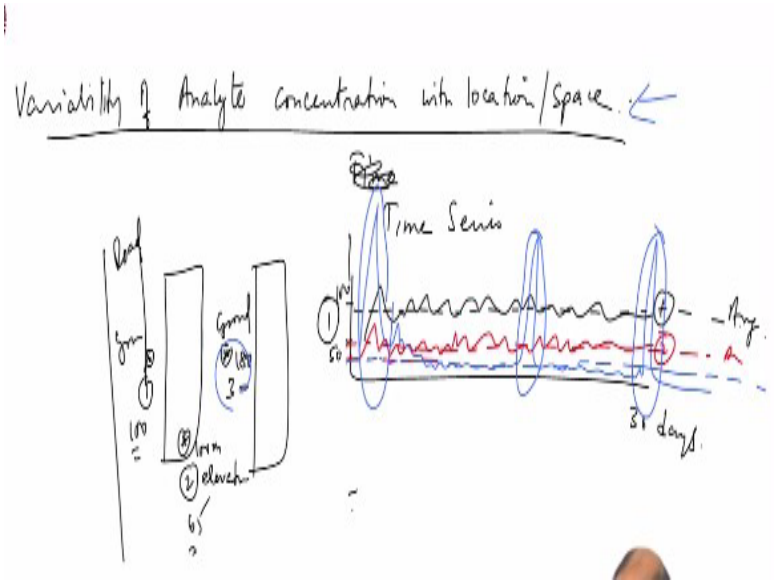
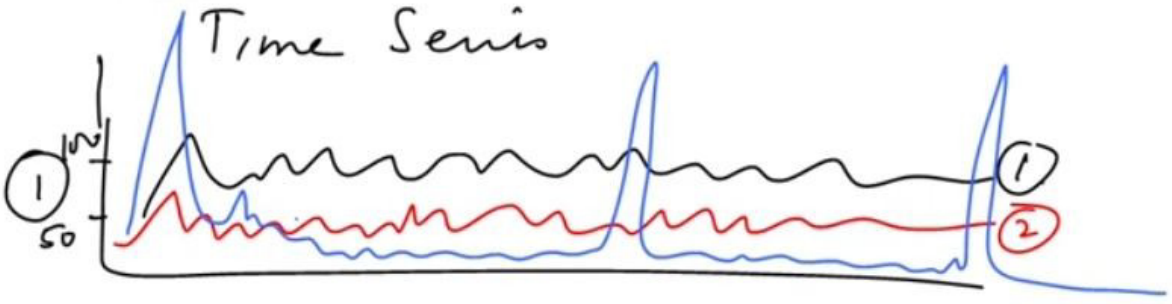
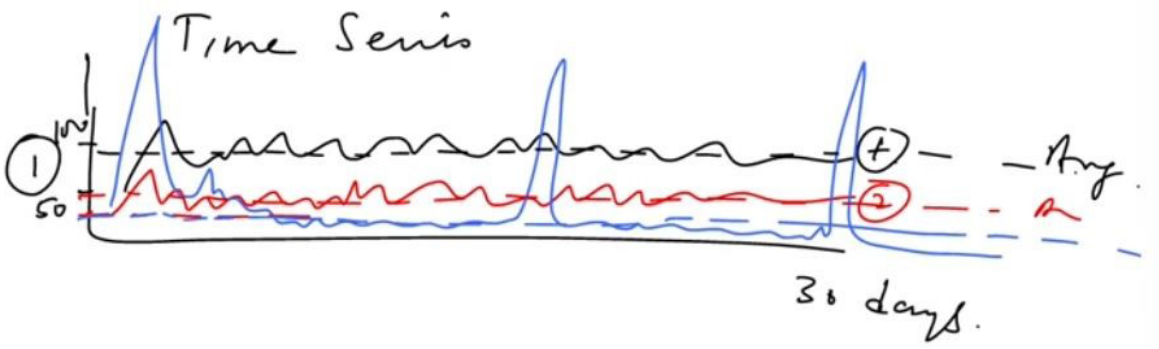


Variability of location or space. This means something so in this case, we are looking at 3 different location sampling 1 which is side of the building, then we looked at sampling site 2 and then we looked at sampling site 3, which is in between buildings on the ground. Sampling site 2 is at 100 meters' elevation. Sampling site 1 is on the ground in front of a road. There is no road at sampling site 3. It says 100, 65, and 180, which means that you can go and look at some specific activity that is happening. So what we do? This is to understand this variation in space, we have to do variation at time, we do a time series. So the sampling location 1, we are looking at time series, which means we are looking at different times. Suppose we get data that looks like this, okay.



What does this mean? Three is low, there are not many sources, but once in a while this suddenly you get a big spike, okay. So from this kind of data, what inferences can you make? There is a reliability to the data since you are doing time series. So when you say time series, I do it for say 30 days, I am measuring it for 30 days, one-month long. I am seeing that there is variation in the data, but more or less if I draw a line, I can draw some kind of a mean line here (sampling 1). It is an average. I can also draw a line here (sampling 2) and say that approximately this is what is happening, the average here.



For this blue line, the average is going to be very small, going to be small compared to this, but there are some big spikes. So when you look at data, when you sample, when you find an anomaly like this, when you cannot make sense of the data, you have to go and do a time series, you cannot sample once and say site number 3 is more, you cannot find any reason why it should be. What was possible reasons could there be that they are high?

At the time when you are monitoring, if there is a high concentration, what possibilities exist? What are possible reasons from your observation of activities here around this building? I can defend this. I can defend sampling 1 that is higher than sampling 2 because sampling 1 is closer to some of the sources which I think are contributing pollution than sampling 2. Sampling site 2 is up in the air. There are no big sources nearby and it is far from the ground, and therefore, I do not expect much this thing okay. This is based on observation.

So when you are living in a house which is on the ground floor, whether it is second floor or tenth floor, there is a lot more dust that comes in the ground floor than in the tenth floor. We get to that later again, whether that is really what does that mean, this is not a blanket statement, but observationally you can at least rationalize it. You can say that I know how to explain it, it makes sense. So there is a spike, very special activity that is happening, say once a week.

It could be things like people are sweeping their entire area and cleaning it. Sometimes people clean roads. They clean roads by taking a blower and they blow okay, that possible, in

IIT, they sweep. When they sweep, there is a lot of dust locally for a short period of time. So in that time, if you are sampling you will see a spike, but it does not happen every day. So in between these 2 building people sweep, they sweep on soil, generate lot of dust. If you are doing sampling during that time, you will see that spike.

It does not mean that there are any other sources, this is not a recurring source, happens once a week or once in 2 weeks or so. So, this is very important to for you to make judgments like this. A sampling objective has to be designed. You cannot take any inference from one arbitrary reading. Arbitrary reading is just a test, the first step in our sampling thing, say is the river polluted, is the air polluted, yes. If it is yes, then you have to conform by time series analysis.

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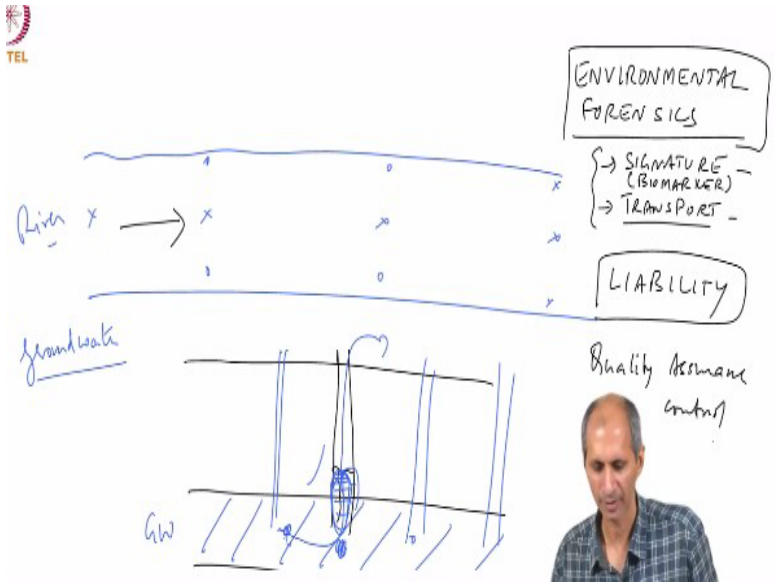

You also have to conform by variation in space which means. Say in a river I have to sample multiple locations initially itself to get some variability in space. I can also sample close to the shore, away from the shore, which may also mean something okay because rivers have a structure, it is not a constant flow throughout. There is some flow, there is variability of flow, in the middle versus that towards the shore, all that is possible and there could be something else near the shore that is causing a slight difference.

So, these are all more refined questions of where you must sample. Again same questions appear for lakes also. Now when you go to groundwater, groundwater is under the soil. How do you sample groundwater? You have to access it. What is the only way to access

groundwater? You have to dig a well and the water will come up a little bit and you sample the groundwater. Here also when you dig a well, water is already here, right?

If you want to sample this position (towards the side of the well), how can you do that? There is no well there. If you want to sample water that is there actually in the groundwater, it is quite possible that there is some amount of water in the well already and it is sitting there for a long time. It may not represent what is the groundwater quality here. So you have to pump out this water and wait further sometime for this water to come up and then sample. So, this is very important.

So this groundwater and much trickier because you are not able to access groundwater wherever you want. The air sampling, I can go wherever I want, technically there is nothing stopping me from doing it and I have to spent more money to go and sample at a particular location in the air or in the water also. The groundwater is difficult because I have to essentially dig up the entire thing and reach the groundwater. So, I cannot do that. I have to draw well, then we have to draw multiple wells. I have to keep on putting hundreds of wells in the area, that is the only way to do groundwater analysis. If you are looking at the same question that we asked in the river, where is the source? Groundwater here is polluted; you have to find out where is the source? The source can be anywhere. The groundwater is not like a river, small flow, it can be a large section that is floating around. So you have to go and make wells in a given area and then make a map of the concentrations and then figure out where the source could be, and it is much more complicated.

You have to understand the hydrology and this is where the analysis of transport comes into question. So there is a field in monitoring and chemical analysis, which is called as environmental forensics. This is a very niche field, niche field means it is a very specific thing. We are calling it forensics because the word forensics means something nefarious, we talk about forensic in a crime scene analysis and that kind of thing, when we are talking about police investigation.

This is environmental investigation, which means that you will answer questions primary question that we are asking is where is the source, what is the source. To find out where the sources is we are making use of information of the flow of the river to figure out that the

source is upstream or downstream and we are looking at the composition, analysis of the chemical to find out whether the chemical from a particular source.

So this two pieces of information that relates to the chemical analysis the competition itself, what we call as a signature. If a signature appears in the sample, you know that that signature corresponds to one particular source only and then we have transport. The signature is also called as a biomarker, it is a marker. Signature is a marker, some things have marker. And transport, so how will it move from the source to the point that we are looking at. So, this transport model is very useful in predicting where it comes. River transport is a simple transport model.

Flow of river water is flowing from point A to point B. Likewise, if you are able to model groundwater flow, you can figure out where will it come from? The concentration is changing in a certain manner you can backtrack and say this is where probably coming from without even measuring, that is the idea. Why are you worried about all this number of samples and using other information to do all this? Why you worry about it, I do not care. I will put thousand monitoring wells and sample.

It is time and cost, both, it is very expensive. Time is there, but the expense is more important, it costs a lot. You will see how much it will cost depending on how we do the analysis and extraction. The cost part of it is also very critical because a lot of the information that you gather from sampling and monitoring is used for what we call in assigning liability. It is a legal thing, which means that if I find the source to be factory 1, I am charging factory 1 is polluting the environment, then they have to do something about it.

They have to pay a price or pay the penalty of cleaning up the rivers or just a penalty. So regulatory agencies will shut the industry down or they will give a large penalty and all that, so which means that you have to able to prove, you are giving a number to somebody, they have to show that this number is correct, liability, which means you have to make extra expense to make sure that your number you are giving to people is correct, means you have to do more quality assurance and all this costs, quality assurance and quality control all this cost money.

To you have a lot of confidence in the number you are giving, the more it costs. So therefore, this is all expensive and therefore people try to use a judicious combination of the environmental forensic principles in order to prove that this is what it is.