Water and Development

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Objectives. The key objectives of this course is to provide a quick introduction to engineers and physical scientists on how water appears as a development need, its basic scientific and engineering processes and the governance and policy context within which it operates. The course is aimed at engineers who want to work in the development sectors as entrepreneurs and development professionals such as coordinators of programs, consultants and designers, or within NGOs, or want to pursue the study of the sector as a researcher. Our focus is largely on drinking water and water for irrigation. The course begins by defining the development context and ends by concrete case-studies. The middle part provides the science and engineering needed to execute the case-studies. We utilize a regional approach to explain the basic stocks and flows such as ground water, and basic units of analysis such as watersheds. We also explain basic interventions in the sector such as tanks and bunds and water supply systems.

Part I: A Development Framework for Water.

1 Development

Environmental and cultural well-being. Predictable, comfortable and cultural existence. Millennium development goals and sustainability goals. Data: Census data and maps. Various graphs and plots. Attributes and their description. Access to drinking water, sanitation, water quality and water for irrigation. Conclusions and the development agenda.

We have of course seen many disasters, some which move rapidly and some which are in slow motion. We have seen, e.g., the disaster of Uttaranchal in 2013, where in the span of 2 days, some 5000 people perished, of which about 900 were pilgrims. Purportedly, this happened because of a severe cloudburst which led to heavy rainfall in excess of 300mm within a few hours, in many places. This caused many landslides and a subsequent loss of lives and property. Much of the Alaknanda valley was cut off from the rest of the world for many days.

A slow-motion tragedy is e.g., the rampant under-nourishment in India, the extent of which is truly remarkable. About 30% of Indian children are under-weight of which about half are under-nourished, i.e., sleep hungry. This tragedy will unfold over the lifetime of a child, where she or he must grow up weaker than the average, fall ill more frequently, perhaps earn less and so on.

There are many questions which normally arise. Is this tragedy preventable? Are the causes purely scientific, e.g., is our farm productivity much less than other countries? Is it economic, e.g., is our economy such that though there is plenty, it is at a price which is unaffordable for many people. We may also ask: what is to be done when disaster strikes? How can we be better prepared and even better, how can we prevent such tragedies.

The objectives of this course are to take a first step in this direction, esp. on matters concerning water. This is not to say that, after this course, you will correctly analyze the issues involved, and that you will be in such a position as to prevent these or to help in minimizing the effects if indeed a tragedy has happened. It is only that, once we comprehend the nature of the problem, of the causes which are natural and which are man-made, then we are better able to design the cure. Another important point is that, the more the social comprehension of the problem, i.e., when more and more people agree on the issues, the greater is the chance of it getting solved.

Let us begin our understanding by what constitutes a tragedy and why do we call it as such. A simple attribute of a "non-tragic" day is that it is predictable and comfortable. In other words, things that you expect happen and which you don't expect don't happen. This may be in small things as well, e.g., if there is a crowd at the canteen tea-shop, then it is not clear when you will get your tea. On the other hand, if there were a queue, it may take longer for you, since you are a strong person who can muscle your way in through crowds. In general though, it would be more predictable to all concerned when they would get their tea. The notion that life should be comfortable is also easy to understand. Much of our life is spend preparing for a comfortable life, i.e., a life where you need not toil. Thus, we use machines to save effort and farmers use tractors. Another notion of comfort is also absence of need. If you are thirsty in IIT, well you just need to enter a building a drink water at the cooler. You surely don't need to find a well or, even worse, dig one. Finally, an important attribute of a non-tragic society is the importance of *culture*, i.e., of transactions and activities which are un-connected with daily biological needs, but of relationships between individuals which are special, e.g., between father and son, between two bridge players, a street singer and her audience. It may even be between a person and a *cultural artefact*, e.g. a book or Fatehpur Sikri. Clearly, a predictable and comfortable life of plenty would still be boring without cultural exchange.

Thus, we may offer a simple definition of **development** as the *desire for and pursuit of a predictable, comfortable and cultural life by an individual for herself and her household.*

Let us see how we can understand the **Millennium Development Goals**, as listed out by the UN in 2000. These were (i) elimination of extreme poverty and hunger, (ii) achieve universal primary education, (iii) promote gender equality, (iv) reduce child mortality, (v) improve maternal health, (vi) to combat diseases such as HIV, malaria, (vii) to ensure environmental sustainability, and finally (viii) to develop a global partnership for development. There is of course, nothing sacrosanct about our definition of development or the UN's, after all, to each his own. However, there are a few things to note about what it does not have. For example, it has only an indirect mention of money, i.e., in the word *poverty*, and even here it is coupled with hunger. Secondly, it has no mention of companies, or production, or for that matter, of consumption, but it has again, an indirect reference through *environmental sustainability.* Next, it has something about education, the reason for which is unclear. Must a *gond* (i.e., tribal from Gadchiroli district) be educated to be considered developed? Presumably, in the UN's world, better education does lead to better development outcomes! Finally, notice the complete absence of any cultural goals.

Let us look at OECD, which is a group of rich countries, and their indices for countries. We see that they have 11 categories, viz., housing, income, jobs, community, education, environment, civic engagement, health, life satisfaction, safety, and work-life balance. Now, these certainly look more interesting since they cover more of what we would call a full life. It also has more familiar items such as incomes and jobs, as well as some cultural attributes such as *life-satisfaction* and some which will need some delving into, e.g., *work-life balance* or *civic engagement.* One must also wonder how these are measured!

An important attribute of development for us will be *sustainability.* Clearly, if life must be predictable, then all our arrangements of a good life should be here tomorrow, as well as next year, as well as for our children. This requirement that *arrangements must be sustainable*, requires us to use natural resources carefully, but even more, make sure that social systems are sustainable too. For example, for your group-library to be sustainable, everyone must pay ones dues, interesting books should be cheap enough, and people must read them fast enough.

Let us look at an important data-set, the Census Data for India, 2011. The census, of course, is a counting of *every person* in India and her individual attributes, the attributes of her household, and finally of her village/ward. Examples of attributes at the individual level are age, worker-status and literacy. Attributes at the household level are income, housing conditions, access to water, and land-holding. At the village level, some attributes are if the village has a post-office, the nearest college and so on. Most graphs of various attributes that you see in the newspapers are *aggregates* of this basic data set, i.e., averages or sums, grouped by district, state, village and so on.

Here are an important attribute related to water: *distance to source of drinking water.* For example, if your drinking water comes from the village well, the distance to the source is say, 100m. However, if your village has fit a pump and a water supply scheme which provides a connection to every household, then this distance becomes 10m.

The above two pictures illustrate the distance to the source of drinking water for rural people, aggregated by taluka. On the left is for the 2001 while on the right is for 2011. Alarmingly, we see that drinking water seems far from sustainable: it seems to be getting farther and farther away! In fact, if we go to Maharashtra's villages, both the sights below are quite common! It is obvious to ask the causes behind this slow-motion disaster and this course is really about this and related disasters and the way out. Important reasons are poor planning, poor policies, poor science and poor social comprehension.

How do urban people do? What appears below is a graph in which every dot represents a district of Maharashtra. On the X-axis, a a measure of the drinking water service levels in the towns and cities of that district. On the Y-axis, we have the number of *formal sector jobs* per 1000 people of that district. We see that (i) about half the districts are doing at

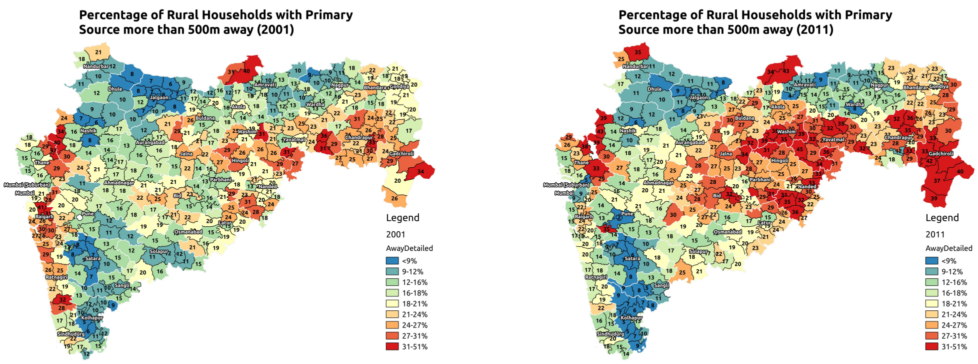

Figure 1: The fraction of rural persons with drinking water farther than 500m.

Figure 2: Drinking water and cooking energy in villages.

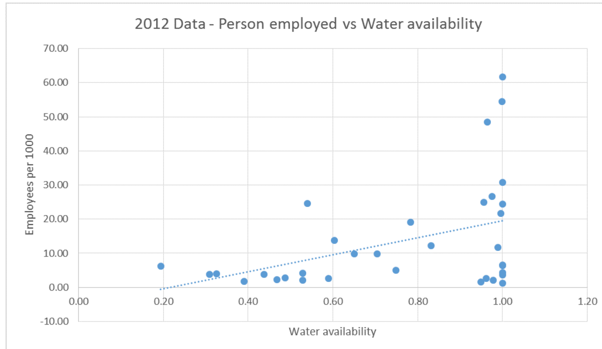

Figure 3: Employees per 1000 vs. urban drinking water service levels, by districts.

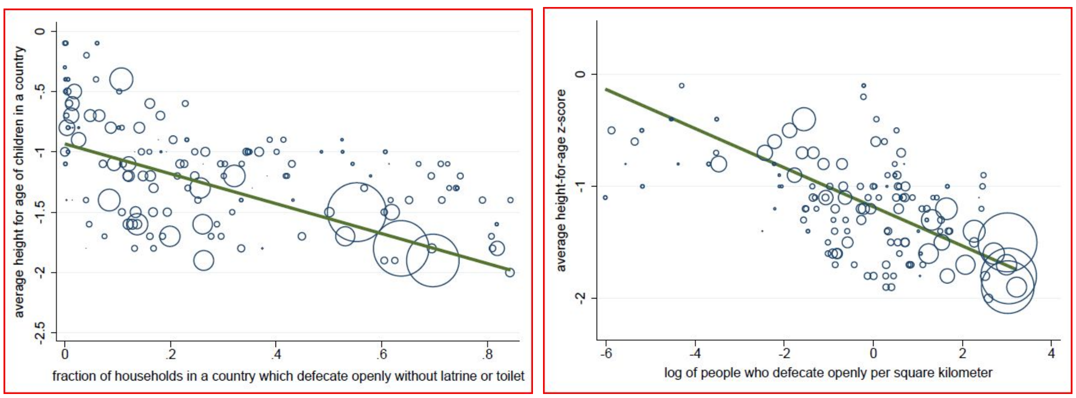

Figure 4: Health vs. Open Defecation (from World Bank)

less that 50%, i.e., urban people do not get water about half the time, and (ii) such districts don't have too many jobs in them.

What are other attributes related to water? There are three important attributes which we will briefly discuss. The first is *sanitation*, i.e., the method of disposal of fecal waste and water after domestic use. One big problem in India, esp. rural India is *open defecation*, i.e., shitting in the open. It has been recently shown that besides being a social problem, Esp. for women, it also has serious consequences for the health of children. In the figure below, we show two graphs from a study of the World Bank of countries across the world. On the X-axis is a measure of the extent of open defecation in the country, while on the Y-axis is a measure of health. The size of the circle is the population size. The large circles on the right bottom are India across various years. The primary reason for this is the biological contamination of drinking water sources caused by fecal matter getting into ground-water sources and also into rivers and streams.

An important use of water is irrigation, i.e., to produce various crops such as cereals, i.e., rice, wheat etc., pulses, oil-seeds, fruits and finally vegetables. Our agricultural year is

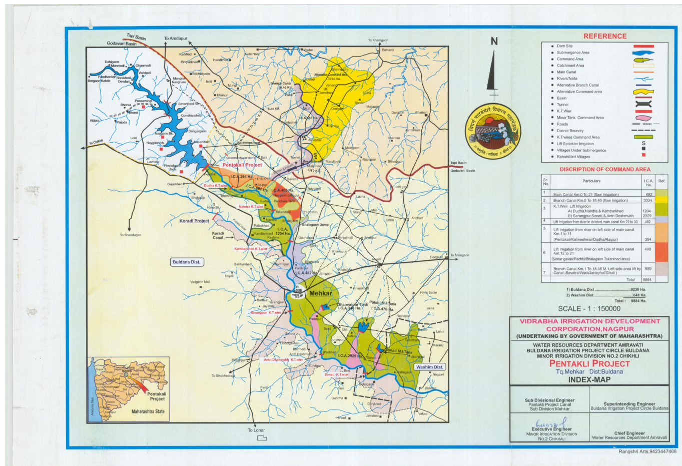

Figure 5: The Pen-Takli irrigation project.

typically divided into three growing seasons, viz., the *kharif* of the monsoons, the *rabbi* in the winter and finally, the summer season. Irrigation is either through canals, or water is taken from rivers, which is called *surface water irrigation* or ground-water, which is accessed through bore-wells and dug-wells. An irrigation system is a complex engineering and socio-economic system where water is first captured in a reservoir and then distributed in canals or through the rivers and streams in the valley. An example system is the *Pen-Takli* system of *Buldhana* district in north-central Maharashtra. The state itself is divided into four agro-climatic regions, viz., the Konkan, Western Maharashtra, Marathwada and Vidarbha. Barely 10% of Maharashtra's arable land is irrigated by surface water. About 50 % is irrigated by ground-water, while the remaining is purely rain-fed. Those farmers with rain-fed lands typically grow only in the kharif season and must migrate or work on other people's lands or seek local seasonal employment. The need to use water for irrigation judiciously is an important objective of the state.

Let us end here by stressing that there is a great variety in the definitions of development, the problems and issues that are seen and those which can be worked on. In the water sector, the development agenda is to provide safe and sustainable drinking water, to dispose waste water safely, to provide for agricultural water, and finally to see that industries get the water that they need and that they do not pollute the environment.

Typical examples of problems which are posed:

(i) Why did a water supply scheme fail?

(ii) What is the structure of a water utility of a city and what are typical problems?

(iii) How do I plan for drinking water security in the district.

iv) Is the cropping pattern in the district sustainable?

(v) How does Jalswarajya or some other government scheme, work?

Exercise. Study the definitions of the census attributes and how they are gathered. Can the MDG attributes be computed from the census data? Do the same for the NSSO data-set.

Exercise. Study the various OECD attributes and how they are computed. Compare and contrast between the MDG and the OECD metrics.

Exercise. Look at the open-defecation graphs from World Bank. What do you think is the mechanism which connects the attribute of the X-axis and that of the Y-axis?

2 The Elementary Structure of Society

The household and its environmental and cultural needs. Sustenance as the key need. The organization of society as State, Market and Civil Society and Assets and Institutions. Efficiency and Equity as auxiliary needs.

The above questions show that good or bad outcomes frequently result from poor design of social structures or poor functioning of these structures. It is therefore necessary to understand social structures from the viewpoint of *agents, roles, processes, mechanisms and transactions* and the role that these play in a particular situation. This connected combination of agents, etc. may be called a *social practice*, or simply a *practice*. An example of a small practice, e.g., is that of a shoe-maker, while a public transport system is a large social practice. Each social practice must serve a useful social purpose and deliver value. It is only this generated value that is shared by the agents who participate in that practice. Thus, while anlaysing situations, we must be able to isolate interacting practices, the value that they aim to generate, and their relationships. Society itself is a network of such practices which interact with each other. A society delivers welfare to its people only if its practices generate sufficient value *and* it is distributed fairly. Thus, it is in this connection that we can analyze a society on attributes of equity, sustainability and efficiency.

Let us now look at a elementary structure of society. For us, the center of our attention is of course, the *individual*, i.e., the well-being of individual human beings. Of course, most individuals stay in households, i.e., groups of individuals who are biologically interrelated and/or who depend on each other for emotional and biological needs. In a way, the household is perhaps the first *collective unit*. In most situations, it is useful to look at a household as the basic unit for our understanding, but not always. For example, the role and conditions of women or girls may be substantially different from those of men or boys in the household. And the proximate causes of these may emanate from outside the household, e.g., these may be cultural or economic.

Having fixed our key interest, i.e., the individual or the household, the development agenda then requires us to find social structures and practices which best suit the interests and needs of the households within that society. A simple categorization of these basic needs are (i) environmental needs, and (ii) cultural needs. The basic environmental needs are for food, water, shelter, and energy to cook food, for lighting and warmth and so on. Much other

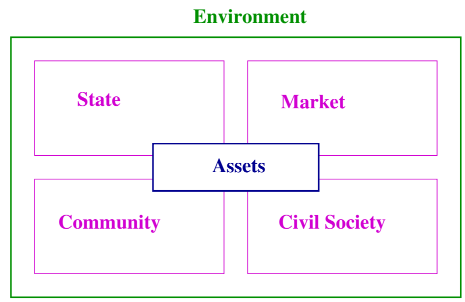

Figure 6: The basic structure of society

needs, such as land etc. are auxiliary, i.e., generated by these basic needs. For example, the need for food may translate into the need for land and for irrigation or for forests to hunt, and so on. The second set of basic needs are cultural, i.e., to do with our relationship with other households and with nature. These can be alternatively described as needs for identity, dignity, community, intimacy and conviviality, narrative and meaning. Life would of course be boring without pictures and jewelry, songs, stories and lullabies. Moreover, life may well be impossible without these, for they may well be used to record, organize, transmit and reward knowledge, e.g., of how to cope with droughts or illness.

One may regard all other so-called needs, such as *sadak* and *bijli*, or education or a ration shop, as arising from these basic needs. In fact, the panoply of social structures, may well be seen as arrangements to provide for such basic needs of the households which constitute our society, or perhaps, a section of households of this society. The *well-being* of different households in a society may be very different. Moreover, this difference in well-being may be systematic, i.e., part of the social structure. Some easily identified sections of society may be doing much better than others. The reasons for this, and why such an condition sustains, are very important for they may impact the sustainability of the basic fabric of society.

For a typical society, there is usually a *division of labour*, i.e., some sort of arrangement, whereby groups of households do a few activities for other groups of households, in return for wages, housing, food, i.e., which leads to a satisfaction of some of its basic needs. This division of labour leads a further specialization into tasks which coordinate the division of labour and the distribution of its benefits. For example, a driver of a bus, needs a road and a bus and also children wanting to go to school. Even more, this division of labour may be possible only because of (i) very specialized *tools* and or (ii) *assets* such as roads and bridges and (iii) *institutions* such as rules of exchange.

Let us attempt to classify social structures broadly, on the basic purpose that they serve. These are the *Market, State and Civil Society*. In addition to these, we also have *Assets*, which may be virtual, such as institutions such as schools or research laboratories, cultural institutions in the areas of music and the arts, or concrete assets such as physical infrastructure. Next, let us quickly outline the working of these basic social structures.

The Market. These are structures wherein which allow the production of commodities and services and its distribution. A commodity is a product which is made for exchange and not for ones own consumption. Similarly, a service is a devotion of one's time, not for one's own direct benefit. For example, shops sell commodities while a barber sells a service. An important commodity is a *tool*, i.e., which is used to produce services or commodities. For example, a truck is a tool to provide *transport*, which is a service.

There are several important features of modern markets. The first is the presence of money, i.e., a token of indebtedness, value and surplus. Money is frequently used in the exchange of commodities and services. When this happens, this exchange is called a *sale*. Before money came, most transactions were either coerced, i.e., forced on one of the parties, or were done in good faith between two parties who would meet regularly. In this case, a settlement would be a continuous process, done perhaps in kind, and over the lifetimes of the agents. Of course, historically, and even now, many commodities were *extracted* from the producers by coercion, e.g., under a threat of violence or social exclusion. An example of this is the *balutedari* system in Maharashtra villages, which was part coercion, part delayed payments, and part un-commodified community service. For many transactions, it was unclear that the object exchanged was really a commodity at all, e.g., the exchange of gifts and presents. Money does make an exchange possible between strangers and also makes its consummation instantaneous, i.e., if a fair price has been paid, then there is no need for either party to keep a history of this to guide future transactions. Thus, money does allow anonymity and mobility.

The second feature of modern markets is the presence of institutions, such as companies, brokerages, regulatory bodies. Brokerage is really an assistant to making a sale, i.e., a service which enables a sale. On the other hand, a regulator is an intervention of the *State* (which we will elaborate next) in the functioning of the market.

The State. The state, also called the *government*, is an agency whose primary objective, in a democratic framework, is to regulate violence, maintain law and order, enable contracts, and protect property rights and individual dignity. Its second role is to enable collective action, e.g., in public transport or a water supply system, a large dam and others, and more importantly, to regulate the activities of market agents and *civil society*. Such collective action allows for a a need of individual households to be met, perhaps more effectively or efficiently or more equitably.

The authority of the state comes through the *constitution* and its elected representatives who enact laws and set the agenda. The bureaucracy and the state's departments and officials are employees who implement the agenda of the state. The judges and magistrates, who are again members of the state, settle disputes framed by the law-makers and uphold the constitution, e.g., by preventing excesses by the state. In an elected form of government, much depends on how the elected representatives are chosen and the constitutional powers of the judiciary and the executive vis-a-vis the legislative. In India, e.g., a district will typically have a Lok Sabha member of parliament. This person is elected in a *first-past-the-post* manner, i.e., the candidate who wins the largest number of votes in the constituency. This need not be the only method, e.g., in colonial times, we had *separate electorates* classified by religion.

The Indian system is a federation system of states with a a central government with two houses, viz. the Lok Sabha or direct representatives, and the Rajya Sabha. Each state has a state legislative body with a representative (MLA) from a constituency which is typically the size of roughly one *taluka* (in Maharashtra). Moreover, there are *division of duties*, i.e., activities which only the center may do (e.g. run the defense ministry), some which only the state may do (e.g., rural development functions), and some are concurrent, i.e., both may do. Water is in the concurrent list where water for domestic and irrigation use, provision of sanitation etc. is handled by the state, while issues related to large rivers and their management are handled by the center.

The transaction of the state with the household is largely as a *citizens* receiving *governance services* in return for taxes and usage fees. The employees of the state are accountable to the legislative body of representatives and through them, to the citizens. Since an MLA may represent over 5 lakh people, the scale of accountability may be quite thin and the familiarity of the MLA with the local issues may not be much. To counter this, the 73rd Constitutional amendment brought three major changes: (i) it set up the *gram panchayat* (GP) as an elected body for each *village*, and the *gram sabha* as the final authority over the gram panchayat decisions, (ii) it produced a list of activities over which the gram panchayat should have primary control, and finally (iii) it set up a mechanism for the GP to access state and central funds and to collect local taxes. Besides this, it also strengthened the *Zilla Parishad*, an elected body at the district level with some limited powers to tax.

After the village, going up, the next important level is the *district*. The administrative head of the district is the *District Magistrate and Collector*. She performs three sets of key activities, (i) all matters related to land and revenue, fines, penalties and regulation, extraction of natural resources and their distribution, sales of goods and so on, (ii) police functions, arbitrage and elementary interpretation of the law, esp. when one of the parties is the state, and (iii) development functions such as water supply, health, education and so on. The three activities are led by the collector, the district superintendent of police (SP) and the CEO of the Zilla Parishad, respectively. All these three positions are key positions of the national bureaucracy, and are manned by the IAS and IPS officers.

The collector is aided by the *collectorate*, i.e., a multi-department office which mimics the departments of the state. Some of these ministries function under the collector, while others function under the CEO and a few under the SP. An important governance structure within the district are the urban local bodies (ULBs) which too have an elected body and an administrative structure headed by either a *Municipal Commissioner*, for large towns or a *Chief Operating Officer*, for small towns. Ultimately both of these depend on the collector for coordination. *The collector is ultimately responsible for the functioning of the state machinery for an ordinary citizen of a given district.*

An important statutory body is the *District Planning Committee*, headed in Maharashtra by the *Guardian Minister*. The secretary of this committee is the Collector. Members of this body are (i) all MPs and MLAs from the district, (ii) a selection of GP and ZP members, (iii) all heads of departments of the administrations, including the police department, (iv) heads of ULBs, and (v) external experts as the DPC deems fit.

Thus, the state appears as a layered bi-partite structure of elected representatives and administrators and officers. A summary table of a cross-section of this structure appears below.

Civil Society. As we have outlined, a household's needs may be classified as (i) basic environmental, or (ii) cultural, i.e., needs of intimacy, conviviality, identity, narratives and so on. Most needs of the second type and a few of the first type are provided by social structures and associations which are neither statal nor market, and which are organized along a different set of attributes. Some examples of civil society structures are religious associations, education institutions, trusts, cooperatives, loose groups withs special interests, collectively owned assets, associations based on community and kinship, membership within caste and sub-caste. Another important civil society organization is an association of professionals, e.g., or barbers or engineers. These must maintain a body of knowledge, seek approval or *charter* from society, train its agents to actually deliver service. Most civil society transactions are historical and based on a collective membership.

It is instructive to analyze each of these associations and classify the basic issues such as membership and attributes involved in a transaction. For example, a community of tribal households provides security, collective decision-making, sense of identity and a sense of common destiny. Another example is a community doctor who, while being a market agent, receives trust, respect and the occasional gift, and in return, is also a source of knowledge and advice. Foremost, she must maintain her *reputation*.

Many development issues may have their roots in existing and rigid civil society structures which may prevent other associations from arising. For example, an alignment of municipal services by community or socio-economic class may prevent a common understanding of citizen-ship and collective civic behaviour to emerge. For example, a division of irrigation water into the head and tail-end farmers may be unequal and lead to poor overall utilization and revenues for the irrigation department. This may lead to a neglect which does harm to the farmer body as a whole. Yet, it may be diffult for the farmers to rally around overall system efficiency.

Poorly performing local or regional cultural associations may allow the market to supply its own cultural products and the subsequent loss of regional role-models. For example, mass produced-recordings of national singers may replace live performances of local singers, altering the ability of a community to entertain itself or form its own narratives. Loss of trust is another symptom of poorly performing civil society associations. Trust is built across agents or sections of society and is based on a sequence of transactions where one party must forgo some immediate benefits so that at the end all sections are better off. An example is a community medical practioner who must maintain the trust by offering correct advice without fees and to be there in emergencies. A loss of trust in a society limits the steps that it can take, for every transaction must yield immediate benefits to all parties. Another common civil society structure are the *village commons*, where a common resource, such as a lake or grasslands, must be preserved through social regulations.

An important role of civil society associations is *social comprehension*, i.e., an understanding of various agents in a society, their roles and behaviours, and the rules governing these. Of primary importance is the comprehension of the state and of the market and their agents. For example, the role of mass-media in promoting certain types of consumption and its impact on local employment, is a matter where better comprehension will certainly help. Similarly, an understanding of the functioning of the Zilla Parishad and a systematic documentation of available civic amenities will guide citizens in their choice of elected representatives.

Thus, our definition of civil society is perhaps, much broader than that by other authors. Along with traditional sociological structures of caste, class and gender, it includes other attributes such as knowledge, social comprehension, citizenship, trust and so on. Further, we should point out that civil society associations and other social structures are in a constant interplay of actions, reactions, penalties, rewards, exclusions, admonitions, and so on. Furthermore, a social agent or a social action is rarely purely statal, market or civil. It is almost always a combination, e.g., the community doctor or the village teacher.

Assets. Our final attribute in the structure of society are its assets. These include physical assets held by the state and market agents, e.g, bridges and highways, factories and office buildings. The most common assets of households are land, the homestead, cattle, a TV, bicycle or a two-wheeler, tools and other productive assets. Assets also includes institutions such as public transport which consists of not only physical assets but also a practice of their use, e.g., the time-table. This practice may well be documented and formalized, and even held secret as *intellectual property.* Almost always, many practices in India are informal and captured in the everyday behaviour of the agents, its schedules and its monthly and yearly rituals. *Thus an asset is a physical or conceptual construction, which is amenable to design, which has a clear purpose, which must be built, and which may be used repeatedly.*

The simplest cultural asset is of course the library. Another important civil society asset is its university. This is again a combination of physical assets, agents such as professors and vice-chancellors, students and researchers, their curricula, pedagogy, published papers, engagements with society and so on. There are intangible cultural assets as well such as individual reputation and prestige, public image of a political party, or brand equity of a company.

Exercise. Identify a service or a product which is now provided by the market but which was earlier provided by civil society. Analyse the chronology and try and explain what may have happened?

3 Agents, transactions and value

The web of agents. The basic agent (in a short loop). The generation of value, the knowledge and rigour. The basic transactions of the state, market and civil society. Agents in long-loops and employees. The need for monitoring and evaluation. Measurements and data-sets.

Having outlined the basic structural components of our society, let us look at the *functional* part, i.e., the mechanics of interactions. The primary functions of a society is implemented via *agents*. At the core, agents are individuals performing certain roles as defined by the social structure, i.e., the state, market or a civil society association. These roles are implemented by a sequence of activities which an agent must undertake. A simple example is that of a cobbler or an artisan. This agent is a market agent and frequently a civil society agents as well. His activities include taking orders for footwear, making measurements, buying materials, using and upgrading his skills, tools and knowledge, delivering the footwear, assessing his deliver and adapting his protocols. The activities of any self-employed professional are similar. Compare this with a labourer, i.e., a market agent who sells labour or a temple priest, i.e., a civil agent who holds a ritual role. While analysing an agent, there are three key points to observe: (i) value generated and delivered and the agency to which delivery is made (ii) value accepted as remuneration or as returns and the agency Fromm which this is accepted, and (ii) the knowledge within the agent and its maintenance. Thus, for example, a labourer delivers labour to a farmer, accepts money from the same, and must maintain good health. On the other hand, a priest delivers spiritual value to a devotee, is paid by the temple trust and must adhere to his recitations and activities.

In modern societies, the activities of most individual agents do not make sense; they make sense only as a collection. For example, a footwear company has many agents, i.e., employees. The division of labour requires that each employee does a particular task, such as measuring feet and selecting suitable footwear, selection of leather, designing shoes and so on. The company itself may be regarded as an agent just as the cobbler, except that it is a purely market agent. Moreover, for market agents typically, the customer both receives value and pays for it, and that too in money. Thus, there is an inherent simplicity in the interface between a market agent and society.

Compare this with the role of a teacher. The teacher delivers value to her pupils, whose parents pay fees to the school, and which in turn pays a salary to the teacher. The state may well be contributing a part of the salary. Even if the school were private and was treated as an agent, the value it delivers to the pupil is much more abstract than the value of immediate satisfaction of a new pair of shoes. This abstract value if possibly an investment by the parent of behalf of the pupil for her future well-being, say as a financial consultant. On the other hand, society may itself have a different definition of a useful education, e.g., it may want to inculcate a sense of membership in regional and cultural associations, e.g., as a good citizen of Maharashtra. Thus, making the school as a market agent will certainly change the curricula within schools and the balance between the collective and the individual values that they will deliver.

We have already seen that the value delivered by an agent may be quite difficult to

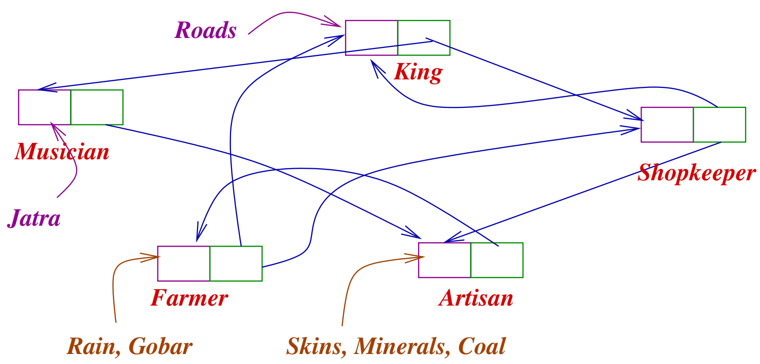

Figure 7: Society as a web of agents

measure, e.g., the value of a security guard for a bungalow. Clearly, the value depends on the wealth of the householder and the risk of theft. The salary of the watchman will depend on a separate set of factors, e.g., the trust in his service, the prevalent market rate and so on. Another important case is that of the value generated by an employee, Esp. in a government. The value delivered by a state department is abstract in many cases, e.g., public health or education, however it must make very concrete payments as salaries. This is ideally done by (i) setting delivery objectives and yardsticks, (ii) designing the structure of the department, (iii) creating roles and job definitions, (iv) setting performance metrics for individual roles, (v) devising pay-scales. However, many state departments may have either not done this exercise, or have an outdated analysis. Moreover, this requires a systematic gathering of data which is both internal and external, and also a notion of *knowledge* within the organization so that it continues to deliver value.

We have now finished our elementary structural and functional description of the structure of society. A typical society is a web of agents serving each other, using environmental resources, generating products and services, and generating assets or using them up. The use of environmental resources brings in the connections to geography, the science of the resource, competition in use, its distribution and its sustainability. Moreover, it is generally not possible to classify a structure as purely market or purely statal; usually it has attributes of several classes.

Thus a a development situation poses an interesting overlay of historical and cultural issues, of state and market agencies, the desires of various sections of society, the geography of resources and the science of sustainable and efficient use.

Exercise. The word *exploitation*, e.g., of lower castes or economically weak members of society, is used frequently by social scientists. Analyse such a situation in terms of the value created by agents and the value received. Why has such a situation arisen?

4 The Development Professional

The diagnosis of poor development-knowledge formation, information asymmetry, institutions, resource constraints. The role of science, engineering, agents and processes. Various mitigation measures and interventions. The roles and skills of the development professional.

Even allowing for a variety of definitions, it is obvious that ours is not a very developed society. Our life-expectancy is much less than our neighbours, our children are undernourished, our women must fetch water from long distances and our girls must walk long distances to reach a school. It is a natural question that what has caused this poor development? This, of course, is the topic for much discussion by politicians, scholars, students, professors, housewives and bus-conductors.

One may ask three related questions: How did it come to be so? What are the exact features of the present? And finally, how do we get out of this state of things? We will drop the first question for later semesters for it requires us to know something about the methods of history, how to articulate it and how to *use* it to analyze the present and argue for a path for the future. Our methodology here would be to describe the present as carefully as possible and try and glean as much about the mechanics of development as is possible. This will then lead us to some corrective actions.

There are generally four common structural weaknesses which scholars have identified and which seem to be frequent causes of poorly performing systems in the development area. These are:

(i) *Poor knowledge formation.* Lack of knowledge formation is an important cause of under-development. This is seen in the poor practices within factories, of farmers and and artisans, but also of the poor quality of education that students receive. It is reflected in the inability of school-age children to measure their own lands or record farm output, or for the college-student to comprehend the role of the collector of the district, or to describe the public transport system in his taluka.

(ii) *Information asymmetry.* Information asymmetry occurs when two agents get into a contract where one party has substantially more information that the other about the situation. A common example is the transaction between a patient and an expert doctor. Clearly, in this transaction, the patient is at a disadvantage since he is unable to judge if the expert doctor is not fibbing. This also happens when a consultant advises a city on its public transport, e.g., on Mumbai's railway system, where many times, the consultant may use tools and models beyond the comprehension of city administrators and engineers.

(iii) *Malfunctioning institutions.* An institution is a multi-agent arrangement within a society where agents perform key roles for socially useful ends such as distribution of goods, e.g., a market, or to mediate between people, e.g., a court. An institution fails when its agents fail to perform, or when people lose trust in it and resort to other institutional or non-institutional means, or when its outcomes are not as intended. An example of a failing institution is the rural school, which is a victim of all the three factors.

(iv) *Collective failure.* Yet another common institutional failure is the *tragedy of the commons* which is variation of a failure to act collectively. Consider, for example, *Kalamb*, a community in Karjat taluka which had a community water supply scheme which gives 1000 liters per day per household. Only when all pay, is the scheme financially sustainable. However, a few richer households want a higher quantum of water than can be met by the scheme. Since this demand is unmet, these households may dig a bore-well to meet their demand and thus opt out of the public scheme. This leads the public scheme to become unviable.

(v) *Resource constraints.* Finally, a resource is a key input to a productive process, e.g., the environmental resources such as water, wood or man-made resources such as steel, or abstract resources such as labour or capital. A resource constraint may be permanent or temporary and may be overcome by other *technological choices*.

These are best illustrated by an example. Consider for example, a cotton farmer from Vidarbha, where farmer suicides have taken a great toll. Firstly, the farmer does not *form knowledge*, i.e., does not document his inputs, observe outputs and develop good practices. Secondly, he may buy seeds and other expensive farm inputs without reading the small print, and without checking if those inputs really apply to his farm conditions. Moreover, at harvest, he may sell it at the *mandi*, where the buyer has far more information about the prices elsewhere than he has. This obviously causes a loss of income and abets his poverty. Finally, there may actually be too little water for him to water his crop, or too few savings to store his harvest till a better price emerges. This may be because of a resource constraint, or possibly because the *institution* called the irrigation system is failing and under poor repair, or that the institution called the bank cannot identify him as a worthy customer for a loan.

Frequently, all these four causes occur in various forms and combinations. A simple example is a missing bridge to cross a river for school-going children. This missing asset may be at once a resource constraint, i.e., the inability of the government to build the bridge or also a knowledge weakness, i.e., an inability of the government to measure the loss of social value and see whether it compensates for the cost of the bridge, or finally, the institutional failure of the government to enforce its own directives to lower level staff.

Knowledge, Science and Technology. The role of science and technology and its practices within a society are important determinants of its development. This is obvious when a resources constraint requires a more efficient use of the resource which is enabled by better science and engineering. Other examples are better vaccines, better designed public transport systems, and more efficient *chulhas*. A more subtle use of science, esp. social sciences, and technology is in the public comprehension of how systems run. If the population of a village understand the bus routes then they will generally ensure that the taluka bus depot addresses their interests.

Science and technology may itself be classified into (i) gadgets and machines, and (ii) processes such as design or analysis. For example, a water meter is a gadget, but a water audit of a city is a process. Most gadgets need to be embedded in processes in which their value is realized. Moreover, the motivation for these processes may not be completely technological, e.g., a water-meter may be a part of an overall policy of a town to install water meters for all households. This may actually be used to make the public water supply scheme financially sustainable. Thus, e.g., if there were adequate water in Kalamb, then the water-meter may well save the community water supply scheme. Thus the costing of an electrical gadget must be understood in relation to the hydraulics of a water supply scheme within a socio-economic context.

There are of course, many situations which are far more complex and which actually need a deeper possibly historical or a socio-political or economic analysis. The nature of interventions in such situations must follow a deeper institutional analysis and may require a broader coalition of agents. An example of this is e.g. the poorly performing higher education system.

However, for a *development professional*, there is much which is amenable to such *developmental* analysis, Esp. at the taluka, district or the regional level.

The basic steps in this are:

(i) identify stake-holders and measure the key attributes of the problem.

(ii) identify the key agents and processes.

(iii) form an inter-disciplinary historical or regional narrative.

(iv) decompose the problem into disciplinary sub-problems.

(v) solve of the subproblems and synthesis.

(vi) deliver value to the stake-holders and charge fees.

Example. Consider the case of *tanker-fed* villages, i.e., those which require water tankers for their daily drinking water requirements. This happens when all the traditional sources of drinking water in the vicinity dry up, Esp. in the summer months, and thus these villages must depend on transporting water from elsewhere or migrating to more suitable locations. These tankers are usually provided by the district administration at great expense. Moreover, since the tanker water is never adequate, and many times not on schedule, it also leads to substantial hardship and anxiety for the habitants.

In Thane district, out of a total of about 1700 villages, the number of tanker-fed villages of Thane district was 160 in 2014. Sixty (60) of these were *repeatedly* tanker-fed, as illustrated below. Analysing further, we see that these were largely in the four tribal talukas of *Jawhar, Mokhada, Murbad* and *Shahpur*. A table of the fraction of tribals in these talukas and also in the tanker-fed villages is given below.

Tribal Fractions				
	Jawhar	Mokhada	Murbad	Shahpur
Tanker	0.97	0.93	0.74	0.62
Taluka	0.97	0.91	0.24	0.35

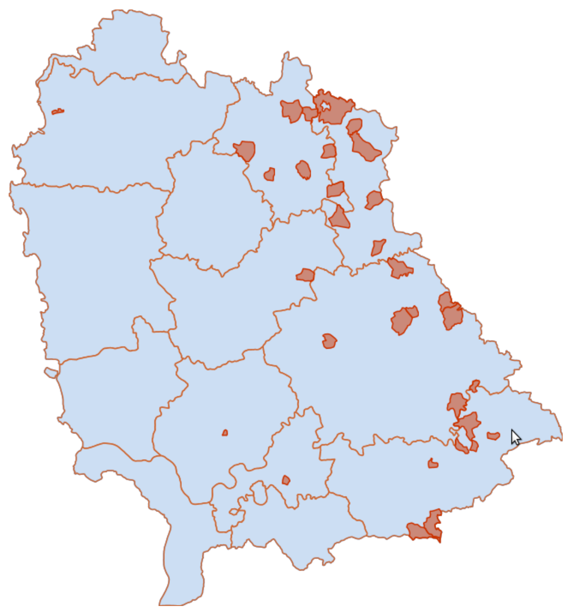

Figure 8: Repeatedly tanker-fed villages in Thane

However, since these talukas are also extremely hilly, we also computed the average elevations of these villages.

Mean Elevations				
	Jawhar	Mokhada	Murbad	Shahpur
Tanker	344	361	123	197
Taluka	320	350	126	132

Further analysis showed that:

- Murbad, Shahpur and Mokhada-Jawhar have different attributes and need different approaches.
- In Mokhada-Jawhar, along with drinking water, basic livelihood is a big problem.
- While communities would like to be independent, in the short-term only a region-wide *bulk-water transfer* solution will work.
- A *natural-resource management* approach is required in the long-term.

Thus, there is a societal part, where the professional must be skilled to probe social structures, measure and formalize the problem, and on the other end, to be able to understand the implementation side and the issues there in. The second skill-set are the *creative* or inter-disciplinary skills of analysing a problem into its various disciplinary sub-components, and the interplay therein, and also to synthesize a complete solution from component-wise

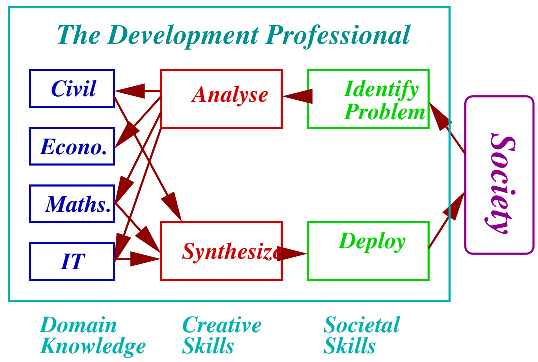

Figure 9: Activities of the Development Professional

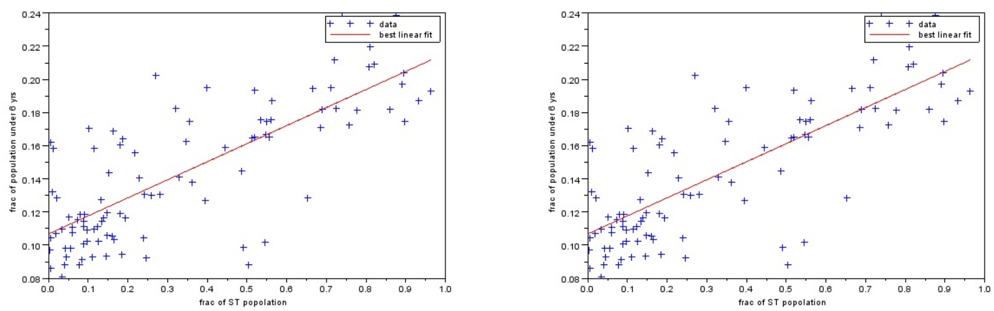

Figure 10: Number of Children vs. tribal fractions and literacy

solutions. The final component is the *traditional and rigorous* disciplinary stuff from where the actual solution comes from. All three skill areas are equally important.

Two words of warnings.

Apparent vs. True causes. The above analysis of drinking water illustrates the use of social variables to help us analyse possible causes. The next step is of course, to propose a mechanism of causation, assess its veracity and then to design for it. Frequently, this will need various iterations for a clear pricture to emerge. A simple example is illustrated by the plots below of villages in Shahpur taluka of Thane district as derived from the Census data of 2001. Each + corresponds to a single village. On both plots, the Y-axis measures the fraction of children (i.e., people 6 years or younger) in the village. For the X-axis, in the first plot is the fraction of tribals in the village, while in the second, it is the fraction of literates. It is for us to analyse what is a better determinant of the number of children in a village.

The question of rigour. We have defined the development professional as a disciplinary engineer, say an electrical engineer, trained in the inter-disciplinary subject of design and analysis of social systems, and as one who utilizes domain knowledge of others, e.g., of civil engineers or economists. In such situations, the development professional must frequently face the question of *rigour*, e.g., what body of rigour does a development engineer have over that of a civil engineer in designing a water supply system. The answer to this, of course, to point out through the census data, the increasing drinking water stress in Maharashtra and the lack of development outcomes vis-a-vis other countries. This clearly points to an inadequate rigour in traditional engineering and its inability to meet this challenge. A simple analysis of the causes (see our article in Current Science, 2012)leads us to the need for a more inter-disciplinary training. Thus, the ultimate proof of rigour for the development engineer is in the design of systems which address these basic problems of *sadak, bijli* and *pani*. The development engineer therefore must focus not only on new domain knowledge, but also mechanisms of its delivery to the people, our ultimate beneficiaries.

Exercise. Identify examples of development problems and see what of the four failures apply to these. Identify the agents, roles, objectives and processes and mechanisms carefully.

Exercise. Suppose that you were hired to improve the hostel-mess service. Go through the development professional loop and make a brief analysis of the issues involved and the activities. Try this out for IIT admissions process.

5 The regional water system

Images of Ghodegaon regional water system. Identification of demand, supply, transmission and seasonality. Identification of various stocks, flows and their dimensions. The assets, their objectives and their design criteria and processes. Listing of agents and processes. Efficiency, sustainability and equity in the regional water system.

Water is of course, a natural resource which is used by households for domestic consumption, by farmers for agriculture and by industries as a raw material for their processes. Moreover, since it is also a geographic resource, its utilization is dominated by regional issues as well as scientific and technological issues. We may broadly classify these into three types.

- **Quality and Quantity**. These are two largely scientific attributes of water. The first, i.e., quality, pertains to the suitability of water for various uses. The most exacting requirement in terms of quality is of course drinking water. This must be free of all pathogens and chemical and biological pollutants. The next level of purity is water for domestic use, and then on for industrial and agricultural use. The quality of water at *discharge points* of industries and city waste systems are also critical for their administration.

  The second attribute of quantity is the amount of water which is available as flows from rivers, steams and canals, as stored in reservoirs, or as moves as ground-water, as falls as precipitation, and as flows from land into streams and rivers.

- **Source, Transmission and Destination**. This is the study of devices of extraction of water from natural sources, its transmission and finally its delivery to points of use. Is is also concerned with the treatment of "used" water and preparing it for discharge. These are largely engineering and logistic problems, and of the design of various engineering systems such as Jack-wells, sewage treatment plants, transmission pipelines, elevated reservoirs and so on.

- **Demand and Supply**. These are socio-economic attributes of the actual quantity and quality of water demanded by various users, e.g., cities and villages, agriculture and so on. It must account for seasonality, economic and technical efficiency of use, regulations on pollution and so on. The supply side is the actual ownership of resources, and the planning and regulation of their use.

Again, this is best explained by an example. Consider below the area of Dimbhe, located in Pune district, as shown in the top panel of the Figure. The second panel, shows a close-up of about 50-100 sq.km. of the area and shows the lay of the land, the key assets, villages and towns. We see the Dimbhe valley nestled between two high ridges on its north as well as the south. The Dimbhe reservoir covers an area of 17 sq. km. and has a reservoir capacity of 350 million cubic meters (MCM). This water is obtained from a catchment of 400 sq. km., and includes the Bhimashankar temple area and sanctuary. Besides this, much of the catchment area is thickly forested, and is also the home for about 50 tribal hamlets with a population of about 30,000. The river, called *Ghod*, flows out of the reservoir and makes its way to join Bhima river. The towns of Ghodegaon (pop. 8000) and Manchar (pop. 15000) lie on this river. Besides this, there is about 10 thousand hectares of irrigated lands and an equal area of partially irrigated or rain-fed lands. Crops include Sugarcane, Maize, Rice, Grapes and other horticultural crops.

Let us now look closer at the down-stream part of the region. In the figure below, in the first panel, we see a close-up of the reservoir, the dam and the gates discharging water. we also see that left-bank canal and the spur of its its bifurcation into a right-bank canal, which actually crosses the river. These two canals wind their way along the two ridges for a distance of 20-30 km. However, most of the farmers who irrigate their lands do it by *lift irrigation schemes*. These are typically from small weirs within the main river-bed, called Kolhapur-type weirs (i.e., KT weirs). These small reservoirs are periodically filled by the discharge of the reservoir into the river. These in turn are used by farmers collectives to design and operate pumping systems which take water to their farms. Other farmers use wells and bore-wells to irrigate their lands. A substantial component of the ground-water is recharged by the reservoir and the river and canal flows. Thus, these farmers are indirect beneficiaries of the irrigation project.

In the next panel, we see a close-up of the neighborhood of Ghodegaon town. We see a KT weir on the river to the north-north-west of the town and also a stream which skirts the town on its north and flows into the river after the KT weir. The sewage of Ghodegaon passes untreated via this stream. On the south bank of the river, at the KT weir, we see many jack-wells and one of this is the pick-up well for the Ghodegaon domestic water supply scheme. The final panel shows a close-up of the KT weir and illustrates its functioning as an in-stream reservoir. The picture also shows the discharge point of the stream which carries the sewage of Ghodegaon. Villages use neighborhood wells for their drinking water and may

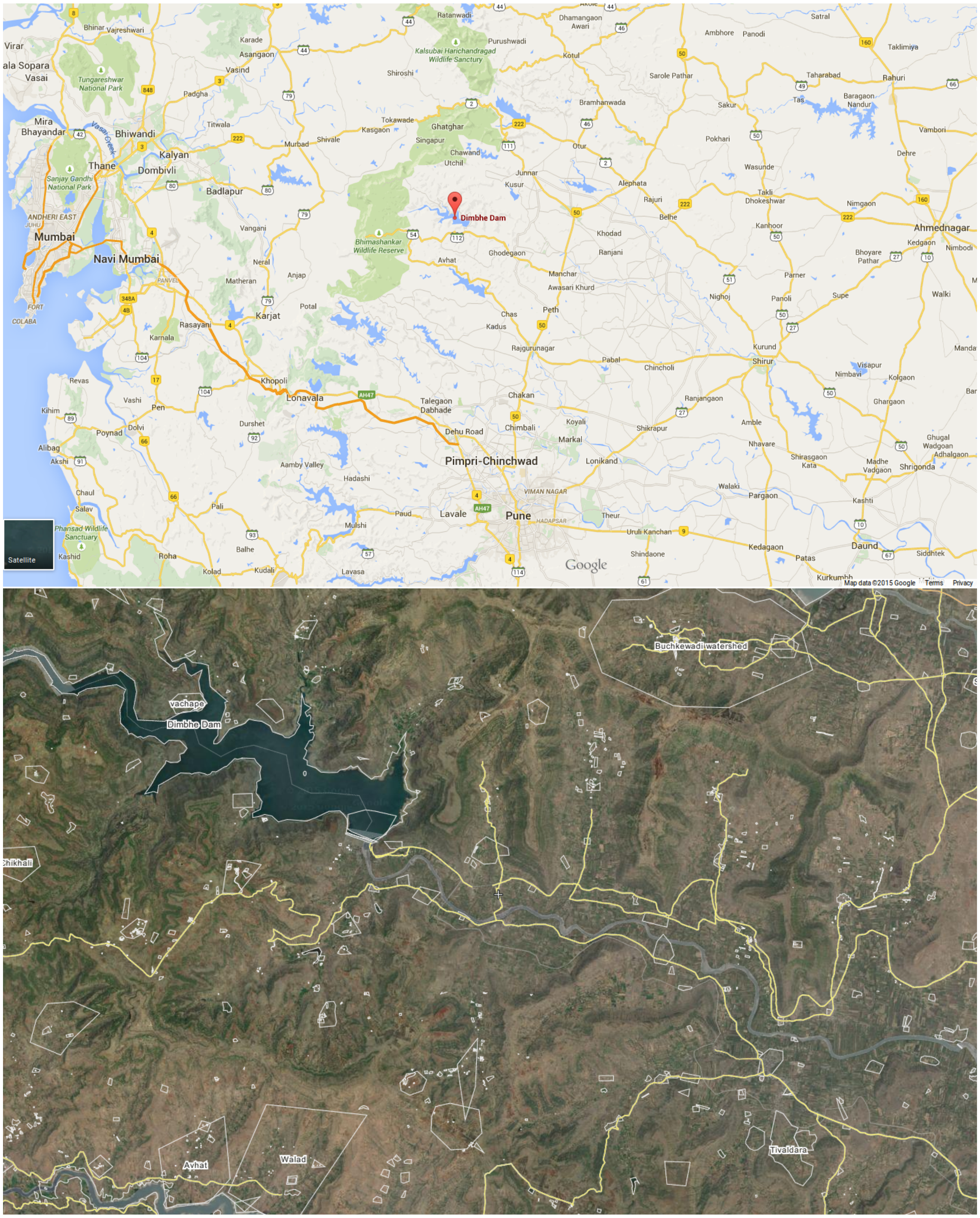

Figure 11: Dimbhe area

Figure 12: Close-ups of Dimbhe Area

have piped water supply schemes (PWSS) which run on these wells. Ground-water may run out in the summers, may be of poor quality in the monsoons, and may have nitrate salts. This salts are likely to be the by-products of the fertilizers used in the surrounding farms, perhaps excessively.

How do we begin the analysis of this complex geographical system? Let us first state the basic subsystems and their key assets and processes.

- **The Irrigation System**. This is a Statal agency which maintains the dam, reservoir and KT weirs. It operates the gates and the canals so that water is made available to the agriculture and the domestic system periodically. It charges user fees from farmers and from domestic users. In Maharashtra, extraction of wells within the *command area* is not charged. The physical quantities which they control or measure are the storage in the reservoir, the schedule of canal and gate discharges, the losses in the system, i.e., the water which leaves the reservoir but which never reaches its ultimate user.

- **The Agricultural System**. This consists of private farmers and their need for water for their crops. The lift irrigation systems which are collectively owned and maintained. It also includes partially irrigated and rain-fed farms. The measurable quantities are crop-water demand, which depends on the crop, the source and the nature of application of water, i.e., whether it was drip or flood irrigation. It also includes fees paid to the irrigation department, energy costs for lift irrigation and for extraction from wells and bore-wells. The key variable is of course, soil moisture, for it is that which ultimately the crop will use.

- **The Domestic Use system**. This constitutes the rural and urban consumer and her systems of extraction from wells or from the river and canal. Its key assets are the engineering at the source, the transmission, the distribution and finally, the discharge. The key variables for this system are (i) ownership of the system, (ii) the level of service, (iii) financial and technical viability of the system, (iv) fees and cess paid to the irrigation system, (v) fees collected from users.

  The irrigation department routinely makes a *water budget* for its reservoirs. Such a budget is shown in Fig. 13 for a collection of medium reservoirs in Thane district.

- **The Physical System**. This is largely the water in the system which must flow according to physical laws and which must transit from one state to another and one location to another. This may be subdivided into four categories of scientific data.

  1. **Laws**. Three primary equations, viz., (i) surface water flow, (ii) ground-water flow, and (iii) conservation of mass.
  2. **Models**. Several empirical systems such as infiltration, precipitation, absorption of water by plants, evapo-transpiration and so on.
  3. **Parameters**. Several natural physical parameters, e.g., the lay of the land, conductivity of soils and other soil parameters, climatic data.

1	**Name of Project**	:	**Musai M.I.Scheme**	**Dolkhamb M.I.Scheme.**
2	Source	:	Local Nalla	Local Nalla
	Location: State	:	Maharashtra	Maharashtra
	District	:	Thane	Thane
	Taluka	:	Shahapur	Shahapur
3	Village	:	Musai	Dolkhamb
4	Catchment Area	:	1.76 Sq.mile	3.68 Sq.miles
5	Average Annual Rainfall	:	107.7"	107.46"
6	75% dependable yield	:	244 Mcft.	-
7	Gross Storage	:	134.26 Mcft.	166.08 Mcft.
8	Dead Storage	:	5.75 Mcft.	9.32 Mcft.
9	Live Storage	:	128.51 Mcft.	156.76 Mcft.
10	Reservation for U/s	:	-	-
11	Annual Gross Utilisation	:	134.26 Mcft.	166.08 Mcft.
12	Top of Dam Level	:	103.00 m.	134.00 m.
13	H.F.L.	:	101.50 m.	132.50 m.
14	F.R.L.	:	100.00 m.	131.00 m.
15	M.D.D.L.	:	89.00 m.	120.00 m.
16	Max. Height of Dam	:	89.00 m.	19.76 m.
17	Type of Dam	:	17.90 m.	Earthen Dam.
18	Length of Earthen Dam	:	Earthen Dam.	213 m.
19	Length of Waste Weir	:	44 m.	60 m.
20	Max.Flood discharge	:	35.52 Cusecs	9284 Cusecs
21	Location of Waste Weir	:	Left side	Right flank
	Submergence area	:		65.59 Hect.

1	**Name of Project**	:	**Musai M.I.Scheme**	**Dolkhamb M.I.Scheme.**
	CANAL			
22	Canal length	:	3.00 Km.	7.17 Km.
23				
24	Canal Capacity	:	12.72 Cusecs	10.21 Cusecs, 4.875 Cusec
25	Area under command	:	600 Acres	196 Hect.
	(Irrigable)			
	I) Gross Command	:	1300 Acres	980 Acres
	ii)Cultural Command	:	1200 Acres	780 Acres
	iii) Irrigable Command	:	600 Acres	496 Acres
	Village benefitted	:	1) Musai, 2) Khaire.	1) Dolkhamb 2) Hedwali
	Village (Taluka wise)		-	3) Bandanpada 4) Sakurli
27	Total Cost of the Project	:	Rs.11,110.00	Rs.17,03,275/-
28	B.C.Ratio	:		2.31

Annual Water Account for Minor Irrigation

Irrigation Year:- 2010-11

Name of Circle:- TIC Thar

Name of Division :- TMID Kalwa Thane	26	27	28	29	30	31	32
Project No.--->	635	636	637	638	639	640	641
Name of Scheme	Adivali	Dolkhamb	Jambhe	Kharade	Musai	Velholi	Hattipada
Type viz. LMI, MI, LIS, ST etc.	MI	MI	MI	MI	MI	MI	MI
District	Thane	Thane	Thane	Thane	Thane	Thane	Thane
Taluka	Shahapur	Shahapur	Shahapur	Shahapur	Shahapur	Shahapur	Vasai
Sub-basin No.	21	21	21	21	21	21	21
1. Designed Storage in Mcum							
a. Gross	2.220	4.703	5.182	2.316	3.800	3.245	2.058
b. Live	2.030	4.439	4.842	2.054	3.640	2.997	1.923
2. Maximum live storage observed in the year	2.030	4.439	4.842	2.054	3.640	2.997	1.923
3. Projected water use in Mcum for							
a. Kharif	0.000	0.000	0.000	0.000	0.000	0.000	0.000
b. Rabi	2.030	4.439	4.842	2.054	3.640	2.997	1.923
c. Hot weather	0.000	0.000	0.000	0.000	0.000	0.000	0.000
d Non irrigation	0.000	0.000	0.000	0.000	0.000	0.000	0.000
e.Total (3 a+3b+3c+3d)	**2.030**	**4.439**	**4.842**	**2.054**	**3.640**	**2.997**	**1.923**
4. Water drawn at canal head for irrigation							
a. Kharif	0.000	0.000	0.000	0.000	0.000	0.000	0.000
b. Rabi	0.945	0.400	1.357	0.950	1.290	1.560	0.300
c. Hot weather	0.000	0.000	0.000	0.000	0.000	0.000	0.000
d Total (4a+4b+4c)	**0.95**	**0.00**	**1.36**	**0.95**	**1.29**	**1.56**	**0.30**
5. Lifts From Tank							
a. Kharif	0.000	0.000	0.000	0.000	0.000	0.000	0.000
b. Rabi	0.000	0.000	0.000	0.000	0.000	0.000	0.000
c. Hot weather	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6. Evaporation Losses	0.179	0.609	0.350	0.195	0.515	0.420	0.240
7. Leakages through dam	0.668	1.887	0.000	0.028	0.625	0.260	1.271
8. Total (4d+5+6+7)	**1.792**	**2.496**	**1.707**	**1.173**	**2.430**	**2.240**	**1.811**
9. Actual Area Irrigated by Canals							
a. Kharif							
i) Area							
ii) Irrigation System Performance (ha/M	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b. Rabi							
i) Area	39.70	18.30	106.90	70.00	65.00	90.13	15.00
ii) Irrigation System Performance (ha/M	42	46	79	74	50	58	50
c. Hot weather							
i) Area							
ii) Irrigation System Performance (ha/M	0	0	0	0	0	0	0
10. Actual Area Irrigated by Tank lifts							
a. Kharif							
i) Area							
ii) Irrigation System Performance (ha/Mcum)	0	0	0	0	0	0	0
b. Rabi							
i) Area							
ii) Irrigation System Performance (ha/Mcum)	0	0	0	0	0	0	0
c. Hot weather							
i) Area							
ii) Irrigation System Performance (ha/Mcum)	0	0	0	0	0	0	0
11. Non irrigation use	0.150	0.550	0.250	0.360	0.140	0.182	0.000
12. Live Storage on 30 th June	0.088	1.393	2.885	0.521	1.070	0.575	0.112
13. Replenishment in the month June							
14. Area Irrigated on wells/rivers/drains in	0	0	0	0	0	0	0

Figure 13: Irrigation and Agriculture water Budgets

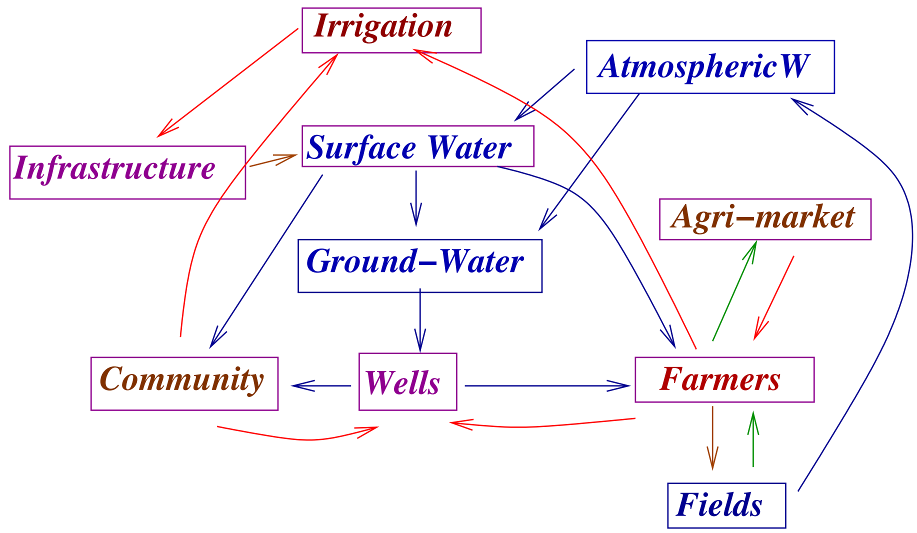

Figure 14: The Ghodegaon Cycle

4. **Parameters and boundary conditions**. Parameters forced by the human systems. This includes location of wells and their extraction, crop water demand and its location, specification of engineered assets such as canals and channels and so on.

A pictorial representation of the system is shown in Fig. 14.The boxes show two different types of entities: various scientific entities which are used in the laws and models of the physical system, and various interacting social associations/structures, as given in the table below:

Agent/Structure	Type
Irrigation	State
Farmers	Civil Society
Community	Community
Agri-market	Market
Infrastructure, Wells, Fields	Asset
Surface water, Ground-water, Atmospheric water	Stocks

Broadly speaking, the water in this system is held either in the ground, or on its surface (such as in reservoirs and KT weirs) or in the atmosphere. These will be refered to as *stocks* in our system. These stocks are accessed and manipulated by human systems through various engineering devices such as gates and channels, wells and bore-wells. Besides this, it flows across these basic stocks as governed by physical processes. For example, atmospheric water fills up the surface water stock as precipitation. A part of this infiltrates and recharges groundwater. On the other hand, much of the water which given to crops is actually converted into atmospheric water through evapo-transpiration.

The objectives of this social system is of course, sustainability, and for that, equity and efficiency. This will mean a choice of crops, a choice of irrigation techniques, tariffs so that the irrgation system is paid for and yet the farmer finds a market for his/her crops. It also means that surface and groundwater do not get polluted and that there is adequate water for domestic use and also for people downstream of Ghodegaon. These objectives then force certain engineering and economic decisions, like schedules for operating canal gates, a better understanding of crop water requirements, a design of water tariff and a state mechanism for its collection.

- **Tutorial 1: System analysis I. Basic Attributes** The *Siddhagadwadi* and *Narivili* village systems. The IIT Bombay campus as a water system.

Part II: The Basic Science of Water.

- **The nature and use of water**. Basic properties and distribution. The basic hydrological cycle. Global and national availability of water. Water for crops, for industries, for drinking. Sustainable water use.

- **The Basic stocks**. Water in atmosphere and water in snow. Ground-water as soil moisture, unsaturated zone and saturated zone. The aquifer and its properties (thickness, layers and yield). The *Gudwanwadi* bore-log. Water in reservoirs. Measurement of various quantities. The Gudwanwadi reservoir.

- **The flows-I**. Rainfall and its measurement. Regional rainfall measurements and estimation of net rainfall. Infiltration, its determinants and excess water and run-off. Evaporation, evapo-transpiration and capillary forces as upward forces. Descent into saturated zone and water table.

- **The flows-II**. Surface flows and its measurement. Open channel flow. Water-table and Base-flows. Sub-surface seepage. Typical stream profile after a rainfall event. Water-table and pond interaction.

- **A simple water balance**. Aquifer, water-table, agriculture, population and rainfall data. The pre-monsoon and the post-monsoon as key epochs. Computation of all flows and stocks. Assumptions on farming practice and its effects. Modelling different situations. Demand as a function of depth.

- **Tutorial II**. Regional rainfall estimation. Water in a channel. Water balance for a drought-prone village in *Sangamner* taluka.

Part III: Regional Water Systems.

- **Ground-water flow**. The aquifer as a grid. Basic properties of a grid element (specific yield, depth, conductivity) and the basic attribute (hydraulic head). Cross-boundary flow, conductivity and Darcy's law. The basic dynamical system. Rainfall and extraction.

- **Steady-state and transient systems.** The linear system with boundary conditions. The saturated monsoon steady-state and the non-monsoon discharge. The well and the cone of depression. The real-life system and its boundary.

- **The Watershed**. Elevation and its representation. The DEM. Surface water flows and the watershed of a point. Watershed delineation. The watershed as a unit of analysis. A supply-demand example from *Mokhada* and *Parbhani*. Basic interventions: wells and *bunds*.

- **The GIS and maps**. Basic maps and their types. Issues of projection, scale and interpolation. Elevation and water-table maps. Conductivity maps. Rainfall maps. The GIS and its architecture. Basic types: raster and vector. Types of vector entities. A GIS dataset-*Pedgaon* and *Thane*.

- **Tutorial III**. Examples of ground-water systems. Watershed computation on maps. Managing a GIS data-set.

Part IV: Engineering.

- **Wells**. The ordinary well and its construction. The well as an extraction and storage device. Yield tests and the well-curve. Elementary analysis of wells. Bore-wells and their construction. Wells through many layers and artesian conditions. The hand-pump and various pumps. The pump-curve.

- **An Earthen-Dam Percolation Tank**. The basic objectives-recharge and storage. The basic engineering attributes of a tank-submergence, alignment, dam. The choice of alignment. The basic structure and attributes of the earthen dam.

- **Area and In-stream structures.** Kolhapur-type weir. Concrete *nalla bund*. Chaining of KT-weirs and CNBs. Gabians. Loose-boulder structures. Farm-ponds, farm-bunding and farm-leveling. Contour trenches and their design. Stability of slopes under moisture.

- **Piped Water Supply**. The basic problem and the solution. Key attributes of the input. The architecture of the solution. The source, the rising main, the MBR and the distribution network. The hydraulic head and the friction equation. Solution of a gravity-fed hydraulic system. Various Issues.

- **Irrigation**. The architecture of an irrigation system. The canal network and the command area. Operation of the canals. Theoretical and actual operations. Ground-water and surface water irrigation. Tariff. KT-weirs and lift irrigation.

- **Tutorial IV**. Capacity of CNBs and KT-weirs. Estimating irrigable lands using contours. Design of a PWS. Design of a PWS with two zones.

Part V: Processes.

- **The Structure of the State**. The basic administrative set-up from GP to the Ministry. Various functionaries and institutions. The ZP and the Collectorate and the District Planning Committee. Different ministries in the water sector and their offices and the state, district, taluka and GP level.
- **Routine Processes and Asset-Creation Cycle**. The project-cycle for a PWS. The expression of demand and the proposal. The technical and administrative clearance. Implementation, M&E and maintenance. The MIS and the annual action plan. The lacunae in processes. The basic structure of a government resolution. The role of programs.
- **A State-Level Program**. The Jal-yukta Shivar program. The GRs and their textual analysis. The background of drought and rural stress. Agricultural water as the key objectives. The key steps and the data used. Critical analysis.
- **A Centrally-Funded Scheme**. The NRDWP. The history of drinking water as a central program. The World Bank and its reports. The design of the NRDWP. Its implementation in Maharashtra. Critical analysis.
- **Tutorial V**. Reading of a case-study and an accompanying paper. Outlining stakeholders, basic scientific, engineering, policy and processes.

Part VI: Finally.

- New directions. Research at CTARA. Areas missing above-Urban Water, Water Quality. Irrigation. Climate change.

Case-Studies.

1. The Gudwanwadi check-dam.
2. The GSDA district level water-balance for Thane.
3. Tadwadi-Morewadi failure Analysis of a PWS.
4. The Anjap-Sugave Multi-village scheme.
5. GSDA data-set and its analysis.
6. Khardi peri-urban PWS scheme.
7. Mokhada regional PWS.
8. Ikhari-cha-pada and Mograj GW simulation.
9. Shahpur DW security planning.
10. RWS policy analysis paper.

11. Maharashtra Sujal-Nirmal analysis-Jawhar.
12. Urban water-Parbhani.
13. Site-visit report of the Jal-yukta shivar program.
14. Rural policy assessment-Shahpur.
15. The Kurlod-Botoshi watershed system.